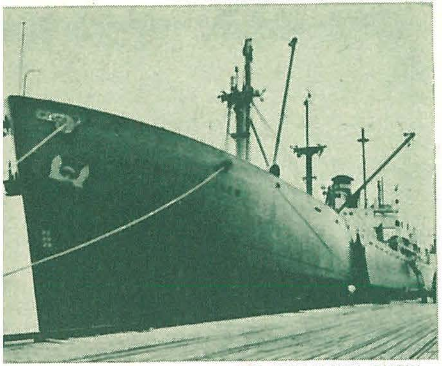
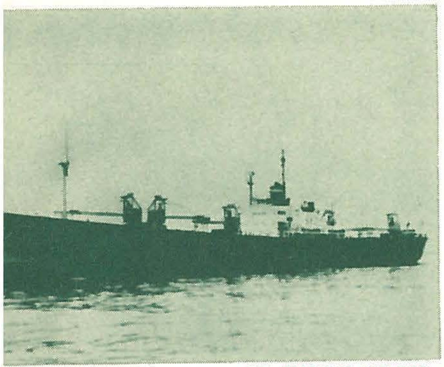
U. S. DEPARTMENT OF COMMERCE
MARITIME ADMINISTRATION

LIBERTY SHIP CONVERSION and ENGINE IMPROVEMENT PROGRAM


SS. BENJAMIN CHEW


MS. THOMAS NELSON

GTS. JOHN SERGEANT

CYCLE
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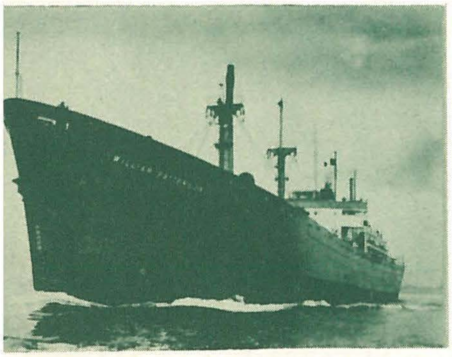
GTS. WILLIAM PATTERSON

PISTON
ENERATOR

CUMULATIVE REPORT
OF PROGRESS
AS OF NOVEMBER 1, 1957

FOR OFFICIAL DISTRIBUTION

Prepared by

MARITIME ADMINISTRATION

OFFICE OF SHIP CONSTRUCTION

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U. S. DEPARTMENT OF COMMERCE
MARITIME ADMINISTRATION

OFFICE OF SHIP CONSTRUCTION

Summary Report on the G.T.S. WILLIAM PATTERSON conversion with Background Data on the Liberty Ship Conversion and Engine Improvement Program.

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INTRODUCTION

The Maritime Administration is currently completing an experimental conversion program under the direction of the Office of Ship Construction involving four Liberty Ships. This program is based upon considerations which can be grouped broadly into two classes: national defense and development in major phases of ship design. A primary objective is the improvement of the quality of the United States Defense Reserve Fleet.

BACKGROUND

National defense requirements were of paramount importance in the studies and investigations which preceded this program. Both the Department of Defense and the Maritime Administration have been increasingly concerned as to the ability of the United States Defense Reserve Fleet to fulfill its purpose of providing a suitable stockpile of defense shipping. In the face of the rapid improvements in undersea warfare techniques during and after World War II, the Department of Defense has repeatedly deplored the lack of speed of the dry cargo ships in the Reserve Fleet and has emphasized the necessity for improving the national defense potential of this fleet. It has been pointed out in various documents of the Department of Defense that existing ships which are incapable of operating with sustained sea speeds of 15 knots should not be considered adequate for logistic support. This presents a serious problem with respect to the provision of ships from our Defense Reserve Fleet since more than 85% of these ships are of the 10-knot Liberty type.

These Liberty ships were built during World War II at a time when many compromises in both design and construction were necessary. (Plate 1 shows a basic Liberty ship with war time cargo.) In the initial procurement of these ships in 1941, the report of the House Committee supporting the special appropriation for 200 ships stated: "It is slow and seaworthy and has the longevity of a modern steel ship, but for the demands of normal commerce in foreign trade it could not compete in speed, equipment, and general serviceability with up-to-date cargo vessels. The design is the best that can be devised for an emergency product to be quickly, cheaply, and simply built. They will be constructed for the emergency and whether they have any utility afterward will have to be determined then." (From House of Representatives, Appropriation to the U. S. Maritime Commission for Emergency Cargo Ship Construction, Report No. 10, 77th Congress, 1st Session, P.4)

While the majority of ships in the active United States merchant fleet meet the 15-knot minimum sustained sea speed requirement, the potential of the reserve fleet as an asset for national defense is negligible from the Department of Defense viewpoint due to the limitation on sustained sea speed stated above. The soundness of this viewpoint was demonstrated in the Korean emergency. Military activities in the summer of 1950 necessitated the withdrawal of all suitable ships from the Reserve Fleet. When all available Victory and "C" type ships were reactivated, the Department of Defense chartered fast ships from the U. S. Merchant Marine. Very few of the 1500 Liberty ships available in the Reserve Fleet were called for reactivation. This limited national emergency demanded the service of practically all the fast ships available under the United States flag. The immensely larger requirements of an emergency of world-wide scope could be substantially implemented only by the unsuitable 10-knot Liberty ships.

In late November and early December 1953, the Maritime Administration conducted a re-examination of the mobilization programs then in existence to determine which, if any, required immediate attention. It was decided that an intensive effort should be made to render the Liberty ship segment of the Reserve Fleet capable of meeting current defense needs.

It was concluded on the basis of a careful study that experimentation should be initiated to determine the optimum procedure to be followed in improving the speed of the Liberty ships. This study included the review of available information and records, the Reserve Fleet requirements submitted by the Joint Chiefs of Staff, the practical considerations involving structural characteristics, speed of conversion under emergency conditions, optimum use of manpower, availability of ships' power plants, and the remaining useful life in existing Liberty ships. It also became apparent from the investigations that extensive alterations of the cargo handling gear on these ships should be made in order to render them suitable for the handling of current military supply, and to increase their effectiveness by improving their cargo handling characteristics. After considering all aspects of the problem, it was decided that the best plan would be to repower these ships sufficiently to provide a sustained sea speed of 15 knots with a minimum of hull alterations and the lowest number of structural and machinery changes. This decision appeared to be a practical way to resolve the conflicting expert opinions.

In January, 1954, a Liberty ship model was towed at the David Taylor Model Basin. The results of these tank tests supported the above decision and indicated that there was an excellent prospect for driving the Liberty ship, with minimum changes, at a sustained sea speed of 15 knots using 6000 SHP. This power plant rating appeared to present the most practical solution for the utilization of available power plants and for the existing spaces. It is also the maximum power to expect from the existing boilers properly modified. In addition, the 6000 SHP rating permits the use of Victory ships' turbines, which were available (in large numbers) from existing warehouse stock. This is also a standard type design readily available from the major U. S.

turbine and gear manufacturers.

Alternate sources of power plants for this program were sought from mobilization industrial planning groups. It was determined that maximum use should be made of existing industrial capacity for adaptation in any alternate Liberty ship re-engining program. Investigations revealed the existence of considerable "tooled up" industrial capacity for the production of diesel engines suitable for a Liberty ship conversion program. In the gas turbine field, also open to the Maritime Administration, machines were currently being produced in the desired 6000 SHP class. The desirability of determining the effect of changes in the hull lines of existing Liberty ships to improve their sea-keeping qualities and to achieve the minimum 15-knot desired speed with the alternate power plant schemes was further indicated by these investigations. It was decided that all conversions should have minimum modifications consistent with the desired service and that all converted ships should be tested and operated experimentally.

A program based on the foregoing evaluations was approved by the Maritime Administrator and concurred in by the Chief of Naval Operations in a letter dated January 28, 1954. This program called for the conversion of four Liberty ships to test the feasibility of upgrading this segment of the Defense Reserve Fleet while also promoting the development of new types of propulsion machinery and cargo handling gear.

INTENT

The major purposes of the Liberty Ship Conversion and Engine Improvement Program may be summarized as follows:

FIRST - To permit the Maritime Administration to evaluate the possibility of upgrading the vast numbers of Liberty ships which are now available in our Reserve Fleets. These are slow-speed 10-knot ships, and while many will be serviceable at 10 knots, the demands of modern warfare require that any ship should have a sustained sea speed of at least 15 knots.

SECOND* To assist the American Merchant Marine in the comparison of these new types of propulsion plants with those already established in maritime service and in the development of new propulsion plants. It is intended that these new engine types will provide not only improved fuel economy but also lower maintenance, replacement, and operating costs.

THIRD - To investigate the possibilities of improving the standard cargo handling techniques and equipment currently in use, in order to reduce in-port time requirements for our cargo ships.

FOURTH - To investigate the sea-keeping characteristics of Liberty ships under actual operating conditions, with and without the lengthened bow, at increased speeds.

The following experimental type conversions have been accomplished in order to secure maximum information and results:

1. EC2-S-8a (BENJAMIN CHEW) - The minimum Liberty conversion without bow change, employs existing boilers but with new superheaters, existing pumps, modified condensers, and a new steam turbine and reduction gear. Retention of the existing bow affords an opportunity for actual investigation of the strength, speed characteristics, and sea-kindliness of existing Liberty ships when increasing installed propulsive power from 2300 to 6000 SHP. Modifications have been made to the cargo gear to facilitate the carriage of military cargoes in accordance with requirements set up by the Military Sea Transportation Service.

2. EC2-M-8b (THOMAS NELSON) - The second conversion includes a lengthened bow to provide sea-keeping qualities that will definitely assure the minimum 15-knot sustained sea speed. The ship has been repowered with geared diesel engines and fitted out with experimental cargo handling gear incorporating cranes.

3. EC2-G-8f (JOHN SERGEANT) - The third conversion also includes a lengthened bow. Existing cargo handling gear has been retained with the addition of two new steam winches at No. 2 hatch. New main propulsion machinery consisting of a regenerative rotary compressor open cycle gas turbine power plant, reduction gear, and controllable pitch propeller have been installed.

4. EC2-G-8g (WILLIAM PATTERSON) - The fourth Liberty ship conversion likewise incorporates an increased bow length, and is fitted out with a free piston generator gas turbine main propulsion unit. Existing cargo handling gear has been retained, as in the third conversion, with the addition of two new steam winches. It should be noted that the original conversion plans for this fourth ship contemplated the installation of a multiple-engine

diesel electric propulsion plant. Due to the highly encouraging response from the marine power plant industry on gas turbine engines, the potential value of such units, and the extreme complexity of the diesel-electric plant proposal in comparison to the other proposals received for these four conversions, it was ultimately considered advantageous to adopt the installation of this second gas turbine unit.

In general, these conversions will provide a basis for ascertaining the best means of re-engining and re-equipping Liberty ships to improve the quality and national defense potential of the United States Defense Reserve Fleet by making these ships more efficient cargo carriers. The use of gas turbine power plants and the adaptation of diesel engines to the use of residual fuels are among the most promising innovations in the recent history of marine engineering. Additional conversions are being studied in order to obtain the maximum practicable degree of improvement in ship characteristics consistent with the state of technological advancement in shipbuilding and engine manufacture.

LEGISLATION

The original estimate requested funds in the amount of $11,100,000 for the Liberty Ship Conversion and Engine Improvement Program in a supplemental budget request dated March 4, 1954. Funds were appropriated for this program under Public Law 663-83rd Congress, dated August 26, 1954. The amount of the original estimate was found to be low due to rising costs and an additional $1,200,000 was made available to this program from ship construction funds not otherwise committed.

Improvements in Hull Structure and Cargo Handling Gear

The first (EC2-S-8a) and second (EC2-M-8b) Liberty Ship conversions involve hull structural and cargo handling experimentation, although the use of residual fuels in a diesel driven ship in the latter conversion is also experimental. Successful results in these areas will contribute to the value of the over-all conversion program as well as the successful performance of the new propulsion machinery types.

1. Seakeeping Instrumentation

Since the principal improvement required to make Liberty ships suitable for national defense is a higher sustained sea speed, the relative merits of obtaining the increased (15-knot) speed by the alternative methods of increased propulsive power in the original hull and increased power in a modified hull are being evaluated in the first two conversions. Extensive instrumentation has been installed on both ships to provide data on ship speed; propeller shaft torque, rpm, and horsepower; wave profile (sea state); roll, pitch, and heave accelerations; and slamming pressures and accelerations at the bow. This will provide a basis for investigating the performance of the original and modified Liberty hulls in terms of ship speed, power, and motions versus sea state.

Model tests conducted during the preliminary studies indicated that the unchanged Liberty ship hull would be operable at 15 knots, provided a 10% loss of cargo deadweight can be accepted, but with unknown seakeeping properties. Since the lack of conversion drydock facilities in an emergency situation may limit the upgrading of Liberty ships to re-engining within the existing hull, it was considered essential to include such a minimum conversion installation in this program.

2. Hull Structural Improvements

The hull alterations incorporated in the last three conversions were evolved after an extensive investigation. It was necessary to eliminate any appreciable alterations of the existing hull structure amidships in order to avoid the imposition of excessive hull structural loads. A final decision was made in favor of the removal of 82.5 feet of existing bow and the addition of a new bow 107.5 feet in length and about 500 tons in weight. The new bow is constructed separately, fitted with a transverse bulkhead to maintain watertight integrity, floated in dry dock, aligned in position, and connected to the rest of the ship by a closing piece about 5'-9" long fabricated in place. (This procedure is shown in the photographs at the end of this report (Plates 3-10).) Other structural changes, including new rudders and reinforcement of the stern frames, have been incorporated as required.

3. Cargo Handling Gear Improvements

Cargo ship utilization in terms of the time required to complete a round trip depends upon the speed that the ship can maintain under way and the time spent in port to load and unload the cargo. It is emphasized here, although previously stated in general terms, that improvement of Liberty ship cargo handling gear to make these ships more suitable for the handling of wartime cargoes with dispatch, was of primary importance from the viewpoint of mobilization potential. A standard Liberty ship has one set of 5 ton booms for each of the five hatches; one 50 ton boom at the No. 2 hatch; and a 15 ton boom at the No. 4 hatch. The booms are rigged with a fixed single-wire topping lift, with the usual chain plate arrangement for adjustment and topping off. The hoist winches are spur geared, steam driven, and are equipped with gypsy heads. A special Working Group of the Navy Department Transportation Committee, set up to study this problem, produced a list of nine items. Five of these were selected, on the basis of priority and the limited funds available, as follows:

(a) Add an additional set of gear at No. 2 hatch.
(b) Replace all 5 ton booms with 10 ton booms and replace existing 50 ton booms with 60 ton booms.
(c) Install a removable 'tween deck in No. 2 hold.
(d) Install working topping lifts on all 10 ton booms powered by electric topping winches.
(e) Install permanently-located wire rope working guys with hand operated winches on all 10 ton booms.

The cargo handling gear of the first (steam turbine) conversion has been modified to include all these improvements.

To foster the development of new ideas in this field, a departure from the orthodox kingpostboom gear was decided upon. Proposals were invited from firms in the materials handling industry for new types of Liberty ship cargo gear. An internal committee set up within the Maritime Administration studied the proposals received and concluded that shipboard cranes offered the best prospects for improved cargo handling without resorting to new systems development. In reaching this conclusion the Committee noted that a considerable development in this field had taken place abroad while United States flag ships held with the orthodox booms and winches. It was therefore desirable to make an installation on a United States ship for evaluation purposes. Crane type cargo gear has been installed on the second (diesel engine) conversion consisting of five cranes, one for each hatch. These are all full revolving, level luffing cranes of 5 ton maximum capacity. The three forward cranes are electro-hydraulic positionable units intended to operate as fixed cranes approximately 10 feet off the ship centerline. They may be moved from port to starboard, thus avoiding the necessity for duplicate units, and two cranes can be brought to bear on the large No. 2 hatch. The two after cranes are of the gantry type, spanning the hatches, and operating on fore and aft tracks, (Appendix (2) is a profile sketch showing the crane installation.) Since these cranes are fully mobile under load, the No. 4 hatch was lengthened as much as possible without major structural alterations. The drives for these cranes are straight electric with magnetic controls on the luffing and hoisting.

New quick-acting mechanical hatch covers operated by the crane booms have been installed on the second conversion only. These are steel watertight covers tailored to fit the crane installations (Plate 11). No changes other than the fitting of an additional set of gear at No. 2 hatch have been made in the cargo handling gear of the third and fourth conversions. Additional details on the first and second conversions are given in the next two sections.

Steam Turbine Conversion - BENJAMIN CHEW

Contract plans and specifications were prepared for this minimum conversion by the Office of Ship Construction, Maritime Administration, which permitted advertising for bids on August 30, 1954, four days after funds were appropriated. Bids were received and opened on October 19, 1954 from fifteen shipbuilders. These bids were priced from $1,079,000 to $2,447,727. A contract was awarded to Ira S. Bushey & Sons, Inc., Brooklyn, New York, as the low evaluated bidder at $1,079,000 contract price on October 29, 1954. The SS BENJAMIN CHEW, MCE 58, arrived at the yard on December 1, 1954, and physical work started immediately with a preliminary survey of hull condition. The bid price of this conversion does not reflect the cost of a conversion if undertaken on a large scale as the steam turbines and gears installed were taken from Maritime Administration warehouses to demonstrate the possibility of economizing on conversion cost by the use of existing equipment stockpiles.

Hull structural and cargo handling gear modifications included in this conversion are described above in detail. (Appendix (1)) is a profile sketch of the ship which indicates, in schematic form, the general extent of these changes. Seakeeping instrumentation is also described above.

The SS BENJAMIN CHEW successfully completed her sea trials in July 1956 and obtained a top speed of over 15 knots. Immediately afterwards she was placed in service for the Military Sea Transportation Service, operated by the United States Lines Company under Bareboat Charter.

During the first seven months of operation she has traveled approximately 29,000 miles. The average speed at sea was 13.5 knots. The low average speed is a result of extremely heavy weather conditions during the first two voyages. Outbound on her third voyage the weather was fair and an average sea speed of 15.5 knots was obtained.

Fuel consumption at sea has averaged 291 barrels per day; 0.92 barrels per mile. This is a high rate of fuel consumption by todays standards and could be improved considerably by a different choice of steam conditions and steam cycle. This was realized from the start, but an efficient plant was not the goal in this particular conversion.

It is too early to report on the sea-kindliness of the Liberty Ship Hull when operated with 6000 SHP. It is a big job to measure and interpret the data which is still being collected.

Diesel Engine Conversion - THOMAS NELSON

The Office of Ship Construction, Maritime Administration, also prepared contract plans and specifications for the second Liberty ship conversion, to diesel propulsion. This conversion was also advertised for bids on August 20, 1954, four days after the appropriation of funds. Bids were likewise received and opened on October 19, 1954 from eleven shipbuilders, at prices ranging from $3,070,000 to $4,773,708. Award of contract was made to the low bidder, Bethlehem Steel Company, Key Highway Plant, Baltimore, Maryland, on October 29, 1954 at $3,070,000 contract price including $29,319 reactivation cost. This cost was subsequently absorbed in the shipyard Master Repair Contract, leaving a net conversion cost of $3,040,681. The MS THOMAS NELSON, MCE 30 arrived at the shipyard on November 19, 1954 and physical work started immediately with inventory and removals.

This ship has been altered structurally to the finer longer bow previously described and shown in the photographs at the end of this report (Plates 3-10 inclusive). Seakeeping instrumentation also has been installed. Appendix (2) provides a schematic indication of the changes made including cargo handling gear.

All of the original propulsion equipment was removed, and two Baldwin-Lima-Hamilton 3000 SHP diesel engines driving through a reduction gear were installed. These main propulsion engines are guaranteed to burn Bunker "C" fuel, the most economical fuel available in world ports, which costs only a little more than half the price of marine diesel fuel. Additional fuel treatment equipment was provided, including dual automatic desludging heavy fuel oil purifiers, and a viscosity control unit which takes continuous oil samples, records sample viscosity, and maintains constant oil viscosity at any desired value over a wide range by controlling the flow of steam used to heat the oil.

The MS THOMAS NELSON logged a top speed of approximately 17-1/2 knots during her sea trials in August 1956. Immediately afterwards she was also placed in service for the Military Sea Transportation Service operated by the United States Lines under Bareboat Charter over the same routes as the SS BENJAMIN CHEW. The operation of the NELSON and the CHEW under the same conditions will provide the necessary information to evaluate the seakeeping characteristics of the original Liberty ship hull repowered to 6000 SHP vs the Liberty ship hull with the extended bow repowered to 6000 SHP.

During the first six months of operation she has traveled approximately 20,000 miles. The average sea speed has been approximately 14.8 knots at 4265 SHP. Fuel consumption at sea has averaged 155 barrels per day; 0.436 barrels per mile.

Comparing the performance of the CHEW and the NELSON, it is interesting to note that while both ships are burning "run of the mine" Bunker "C" fuel, the NELSON has averaged less than half the fuel consumption of the CHEW, yet making better than a knot more speed and carrying more cargo.

The evaluation of the new type cargo handling gear installed on the NELSON under actual commercial operating circumstances is under the direction of the Maritime Cargo Transportation Conference of the National Research Council.

Engine Improvement Program

The conversion of both the BENJAMIN CHEW and the THOMAS NELSON utilized conventional power plants which had been well proven for ship propulsion, although the adaptation of the diesel engine to burn unrestricted residual fuels is new, not only to the marine industry but also to the diesel industry as a whole.

The Engine Improvement Program is based upon the conviction that technological advances make possible the development of gas turbine types of ship propulsion plants capable not only of higher efficiencies but also of lower maintenance and operating costs than the conventional steam turbine power plants generally in use in the United States Merchant Marine. This program includes a current phase and a planning phase due to continuing research and development in power plant technology. The third and fourth Liberty ship conversions primarily involve propulsion plant experimentation. The selection, procurement, installation, and evaluation of these plants constitutes the current phase of the Engine Improvement Program.

On February 15, 1954, directly following the Maritime Administrator's approval of the over-all conversion program, inquiries were sent to leading heavy equipment manufacturers throughout the United States requesting proposals to furnish gas turbine propulsion machinery for the

-engining of Liberty Ships. The manufacturers were given complete
gineering latitude in the development of their proposals subject to
eting certain basic operational concepts. These limitations required
at units be capable of burning Bunker "C" fuel, that the installation
guaranteed for one year, that a high thermal efficiency be obtained,
at the existing machinery in the Liberty ship be retained wherever pos-
ble in order to limit the conversion costs, and that a normal continuous
t put rating of 6000 SHP be met. The manufacturers were further advised
at upon receipt of their proposals a complete evaluation would be made,
d that if Congress appropriated the funds, a contract would be negotiated
the basis of cost, reliability, weight and space considerations, simpli-
ty of operation, minimum maintenance requirements, and maximum operational
exibility.

These inquiries evoked considerable interest in the heavy
uipment industry, and in May, 1954, the Maritime Administration received
oposals from eleven companies, many proposals including several proposi-
ons entailing various refinements to the gas turbine cycle. Three
jor types of gas turbine power plants were offered; namely, rotary com-
essor open cycle, rotary compressor closed cycle, and free piston gen-
ator open cycle. Several types of transmissions were offered including
ectric drive, reversing reduction gears, double reduction gears with
ntrollable pitch propeller, and gas turbines with and without reversing
ements.

1. Rotary Compressor Open Cycle Gas Turbine Plant

An Evaluation Board consisting of Industry and Government members was appointed by the Maritime Administrator and all proposals were submitted to this Board for study and evaluation. On the basis of the aforementioned requisites, this Board recommended as the first gas turbine propulsion installation the rotary compressor open cycle type with double reduction gear and controllable pitch propeller, as proposed by the General Electric Company of Schenectady, New York. This company has had considerable experience in the construction and operation of rotary compressor open cycle gas turbine power plants for locomotive, gas pipe line, and stationary power plant service. This plant is the largest installed unit of its kind in the field of marine propulsion.

(Appendix (3) is a simplified flow diagram of the gas path in this power plant.) Incoming air is led to the compressor through an inlet hood and is compressed to 72 pounds pressure in passing through 14 stages of fixed and rotating blades. The compressed air is then heated by passing through a heat exchanger (regenerator or recuperator) which is essentially a series of finned plates with hot exhaust gases passing on one side and the air to be heated on the other. From the heat exchanger, the compressed heated air is led to the fuel oil burners (combustors) where fuel is added, combustion takes place, and the air-fuel mixture is adjusted to provide the desired outlet temperature. The combustion gas then flows through two independent turbine wheels in succession. The first (high pressure) turbine drives the compressor, and the second (low pressure) turbine drives the ship's propeller through a reduction gear. To complete the cycle, the turbine exhaust gas is led through the low-pressure side of the recuperator, which heats up the compressed air, and then to the atmosphere through a waste heat boiler, which provides small quantities of steam for heating, galley, and miscellaneous purposes. Additional features of the gas flow patch include intake baffles to remove entrained salt water and and exhaust-gas-fired superheater.

The blades of the controllable pitch propeller may be reversed to obtain astern power for the ship without reversing the direction of rotation of the propeller shaft. This type of propeller provides an infinite number of possible pitch settings between the limiting positions of full ahead and full astern, including zero pitch. Optimum settings may be determined by experience for all conditions of operation. A shaft brake capable of absorbing 10% (600 SHP) of the normal continuous plant output (6000 SHP) is incorporated. This feature permits low-power operation of the plant without propeller rotation, and provides improved dockside maneuverability. An innovation to the American Merchant Marine is the provision made to control shaft horsepower and propeller rpm from the bridge as well as the engine room. The propulsion plant and propeller controls are integrated so that the ship speed can be controlled by a single lever from either the bridge or engine room consoles. Independent control of the propeller is also provided through a separate lever on the engine room console, permitting operation of the propeller above full-power pitch under light ship conditions if a high ship's speed is desirable. In view of the complete dependence of this ship on a single propulsion unit, an emergency propulsion steam turbine has been provided in order to avoid disabling the ship by a minor derangement. The turbine and its piping are permanent installations, but the turbine is not connected to the main reduction gear during normal operation. The connecting pinion is carried on the bulkhead, and can be installed in one hour. Provision for the treatment of fuel oil to avoid the adverse effects due to depositforming elements found in residual fuels and to contamination of the fuel by sea water is included in the main propulsion plant accessories. In addition, dual wet and dry cleaning systems are installed to minimize the effect of fouling on the compressor, turbines, and heat exchanger surface.

2. Free Piston Generator Open Cycle Gas Turbine Plant

The Evaluation Board then made a second selection from the various gas turbine proposals for installation in the fourth Liberty ship conversion. It was determined that the free-piston generator gas turbine combination proposed by the Cleveland Diesel Engine Division of General Motors Corporation, Cleveland, Ohio offered the best possibilities. This type of propulsion equipment has exceptional possibilities for future ship power plant applications, since the required power can be obtained with various combinations of gas generators and different size turbine units. The free piston generator gas turbine power plant also has considerable potential in mobilization planning, since very little critical material is required due to the relatively low operating temperature, and it can be manufactured on a mass production basis. Its overall thermal efficiency promises to exceed that of any existing conventional ship's power plant.

Although the free piston principle is relatively new in the United States, it has been used extensively in Europe, both in air compressors and gas generators. The General Motors Corporation free piston engines designed on the basis of original Pescara patents by SIGMA of France (Societe Industrielle General de Mechanique Appliquee) are combined with Alsthom turbines in this plant. SIGMA has had successful experience in installations of this type in power plants ashore and in a limited number of propulsion plants on both merchant and naval vessels. There is no similar service experience with free piston gas turbine propulsion machinery by manufacturers in the United States. The Office of Ship Construction considered this an ideal opportunity and an example of how American Industry should adopt those European developments which may have merit.

Appendix (4) illustrates the operating cycle of a free piston gas generator, and Appendix (5) shows the six free piston generators combined with two turbines, re-

duction gear, propeller shaft, and propeller
The gas turbine propulsion plants selected for the current phase of the Engine Improvement Program are new to U. S. merchant service. However, they do not represent the most advanced state of the gas turbine art since conservative selections were made for these initial installations in order to obtain maximum assurance of reliable service operation. Consequently there is a considerable amount of development "potential" available for further improvement of ship performance by the continued development and evaluation of these new power plants. These results may then be incorporated into additional conversions.

Rotary Compressor Open Cycle Gas Trubine Conversion - JOHN SERGEANT

In order to acquaint the Industry as much as possible with the new developments sponsored by the Maritime Administration, the firm of Gibbs and Cox, Inc. of New York City was selected as the design agent on September 22, 1954 to prepare the contract plans and specifications for all shipyard conversion work, under Maritime Administration instructions to follow the general concepts of the first two conversions in minimizing the actual modifications to the ship and retaining existing cargo handling gear. These restrictions were imposed in order to accomplish the work within the budget limitations.

On September 24, 1954, less than a month after the appropriation of funds by the Congress, a letter of intent was sent to the General Electric Company for the purchase of a 6000 SHP regenerative type open cycle gas turbine main propulsion plant as described in detail above. The letter of intent was superseded by a formal contract. The design of this plant is basically similar to those with which several years of service experience have been gained in shore installations.

On September 29, 1954 a contract was awarded to the S. Morgan Smith Company of York, Pennsylvania to supply the controllable and reversible pitch (CRP) propeller system, including special shafting and hydraulic controls. The selection of this propeller was based on a detailed study of the available designs. Considerable weight was given to accumulated service experience with these designs in the final selection.

The Newport News Shipbuilding and Drydock Company was awarded a contract on July 27, 1955 for the complete conversion installation at a contract price of $2,450,000. This price does not include the cost of reactivating the vessel from the laid-up fleet, estimated at $125,000 which is provided for in the Newport News master repair contract. The SS JOHN SERGEANT MCE 63 arrived at Newport News on September 16, 1955. Physical work began on September 20, 1955 with inventory and removals following the passage of a hurricane fringe. No damage was sustained from this storm. Modifications to the hull structure of this ship include the bow change described above. The installation of additional cargo handling gear has also been previously described.

The JOHN SERGEANT successfully completed her sea trials in September 1956. A maximum power speed of over 18 knots was obtained. Immediately after the trials she was placed in service for the Military Sea Transportation Service operated by the United States Lines Company under a General Agency Agreement. The vessel has completed three voyages to Northern European ports and has had no forced detentions because of power plant mal-function. During the first 27,000 miles she has traveled, the average sea speed has been 15.4 knots. Fuel comsumption at sea has averaged 236 barrels per day; 0.677 barrels per mile.

Free Piston Generator Open Cycle Gas Turbine Conversion - WILLIAM PATTERSON

A second design agent, J. J. Henry Company, Inc. of New York, New York, was awarded a contract on September 22, 1954 for the development and preparation of contract plans and specifications covering the fourth Liberty ship conversion. This contract also included engineering consulting services, assistance in the preparation of procurement of purchase orders, and technical contact with all vendors to insure that the purchased items fitted the over-all design. Again, certain limitations were imposed on the design agent in order to accomplish the conversion within budget limitations.

The award of contract was made by letter of intent dated October 6, 1954 to the Cleveland Diesel Engine Division of General Motors Corporation for the free piston generator gas turbine propulsion plant. This letter was superseded by a formal contract.

A contract was awarded to the Bethlehem Steel Company, Key Highway Plant, Baltimore, Maryland on August 9, 1955 for the completion of this conversion installation at a contract price of $1,857,999. Reactivation work is also required at an estimated additional cost of $202,001 which is provided for in the yard master repair contract. The SS WILLIAM PATTERSON MCE 48 arrived at Baltimore on September 18, 1955 (plate (12)) and inventory of the ship was started immediately. Modifications to the hull structure and the installation of additional cargo handling gear on this ship are similar to the third conversion.

The propulsion plant of the PATTERSON consists of six free piston gas generators, each rated at approximately 1200 gas horsepower, and two 3000 SHP reversible gas turbines connected to the ship's propeller through a double reduction, locked train, marine reduction gear. The free piston generators operate on the two stroke diesel cycle using Bunker "C" oil for fuel. Each gas generator has two opposed pistons in a single power cylinder. These pistons compress their own air for scavenging and charging the power cylinder. They also store the energy required to halt their outward movement and return them in an inward direction for the next combustion stroke. Power is produced in the form of moderate pressure and moderate temperature gas which is used to drive the gas turbines. The free piston gas generators are arranged side by side and discharge gas into a common receiving manifold from which gas lines lead to each turbine.

The common gas receiving manifold is self-supporting and provided with expansion joints of the bellows type made of laminated stainless steel corrugations. The piping material is carbon-molybdenum steel.

The exhausts from the turbines are independently led up through the smoke pipe.

The air for combustion and scavenging of the gas generators is taken from the engine room space at the discharge point of the four mechanical draft fans supplying air to the engine room.

The gas generators are started by air supplied by eight storage tanks charged by four motor-driven air compressors delivering air at 600 psi. Air storage tank capacity has been provided for eighteen starts; that is, three starts per gas generator. A small diesel-driven air compressor is installed for dead-ship starting.

Light fuel oil (diesel oil) is used for starting the gas generators. After a short running period, (up to 5 minutes) the change is made to residual fuel oil (Bunker "C").

The gas mixture generated is first by-passed to the atmosphere until steady operation is obtained, then the gas is directed to the turbines where two control valves per turbine apportion the gas flow to the ahead and astern stages. By varying the positions of the control valves, any desired partial or full power ahead or astern can be obtained. This characteristic allows for very quick changes in power; five seconds is all that is required to shift valves from full power ahead to full power astern, but, naturally, practical operating conditions will dictate a longer time. One of the reasons for adopting this type of control valve is the fact that the gas generators cannot operate below 30% of their normal rated gas delivery. When long periods of time are required at less than full power, one or more gas generators can be shut down, depending upon the power demand, in which case the other gas generators perate near their full power point.

The residual fuel oil is taken from the fuel oil settling anks, heated, and sent to the purifiers. As much as possible of the ater and foreign matter in the fuel oil is thus removed. Normally, he purifying system functions with one purifier in continuous peration. After purification the heavy fuel oil is further heated o obtain at injection a kinematic viscosity of from 11.5 to 15.5 entistokes (67 to 85 SSU).

The light fuel oil used for starting is also used for ooling the injectors. No cooler is necessary to lower the light uel oil temperature as it is re-circulated through a day tank of a ize sufficient to cool it by surface dissipation.

The gas generator power cylinder walls are lubricated with eavy Duty, SAE40, lube oil from attached lubricators. The oil consumption for this purpose is approximately 22 pounds per hour at full ower (6000 SHIP).

The gas generator power pistons are oil cooled with the same rade of lubricating oil used for the turbines and reduction gear. The iston cooling oil system is divided in two independent branches, one or each three gas generators. Each branch consists of a sump tank, otor driven pump, strainer and cooler, with the necessary accessories uch as temperature regulators and alarm connections.

The power cylinder and compressor air oil delivery valve lates are jacketed and cooled with fresh water. The cooling system onsists of two motor driven pumps, two coolers and one common expansion ank. One pump and cooler are standby units.

The turbine and reduction gear lubricating system is a ombined pressure-gravity type and does not differ radically from the sual steam turbine practice.

The lubricating oil coolers, piston oil coolers, and jacket ater coolers are serviced by a sea water circulating system consisting f two motor-driven pumps (one of which is a standby unit) with the usual igh and low suctions and emergency connection from the fire pump. The system is arranged so that the pumps discharge first to the lube oil coolers with part of the total flow by-passed through an orifice valve, the total flow passes through the piston oil coolers, next through the jacket water coolers and thence overboard.

The main propulsion plant control system involves some features hich are not normally found in other installations. Two rotary pumps, ne a standby, take suction from the reduction gear and turbine oil sump tank and deliver part of the oil to the control board to actuate the pilot system. The rest of the oil is branched off to actuate the power system. The pilot system operates at a pressure range of 26-58 psi, and the power system operates at 110 psi. From the control board the pilot oil is led to the turbine servo-motors and to the gas generator fuel rack controls. The servo-motors are provided with the usual hand adjusted pilot. The power oil after passing through an accumulator is led to the power relay cylinders that operate the turbine control valve. The power relay cylinders are of the usual type with pilot valve and differential lever to avoid "hunting". A branch of the power oil system is led to the turbine control mechanism which is acted upon by the turbine lubricating oil pressure and by the overspeed governors. The oil is next led to the gas overpressure cylinder, each gas generator's overstroke cylinder, and finally the fuel pump.

One hand wheel at the control board operates the plant for all ranges of power, ahead and astern. With the gas generators idling and by-passing the gas to the atmosphere, the turbine control valves are in a midposition so as to proportion the gas flow to the ahead and astern wheels so that no rotation either way will result. The main gas supply valves at the gas generators are opened and the atmosphere by-pass closed, feeding the gas mixture to the turbines, which remain stationary. When the hand wheel on the control board is turned in the ahead direction, the turbine control valve throttles the gas to the astern wheel, so that the torque of the ahead turbine wheel predominates and the turbine begins to rotate in the ahead direction. The progressive decrease of the passage area toward the astern turbine causes an increase in the gas pressure. During this period of regulation the gas generators are running at minimum delivery which, as stated previously, corresponds to about 30% of normal full load power.

As soon as the gas passage toward the astern turbine is completely closed the relay between the operating station and the gas generators comes into action and increases the quantity of fuel injected. As the hand wheel is rotated further in the ahead direction, the delivery and the gas pressure are increased up to full load.

To reduce power these operations are reversed. The gas pressure and delivery are first brought back to minimum valves by reducing the quantity of fuel; then the passage to the astern turbine is gradually opened.

The astern power is controlled by the same handwheel, turned in the opposite direction. A similar control board located in the pilot house provides a simple means of maneuvering directly from the bridge.

When any abnormal operating condition exists, such as severe overspeeding of the turbine, low lubricating oil pressure to the turbine, or excessive gas delivery pressure, the plant will automatically secure by cutting off the fuel supply to the gas generators. The turbine overeed governor will first try to prevent overspeeding by modulating the urbine control valves admitting gas to the turbine astern wheel before mpletely cutting off the fuel to the gas generators when overspeeding aches approximately 10%. An overstroke of the pistons in any one gas nerator will also secure the fuel supply to the injectors of that one s generator.

When a gas generator is secured, the pistons travel to near eir outer dead point by pneumatic action. To start the gas generator r under pressure is rapidly admitted to the bounce chamber (outboard ce of the compressor piston) forcing the pistons together. This mpresses air in the compressor cylinder for scavenging and charging e power cylinder and also compresses the air in the combustion space fficiently to ignite the fuel then injected. The pistons are forced art by the burning fuel thus compressing air in the bounce chambers ich store sufficient energy to return the pistons for the next power roke.

Maintaining the correct compression of the combustion air for l loading conditions is one of the most important functions of the ee piston gas generator control. The return of the pistons toward ner dead point must then be the proper one at all times, and to obtain , a bounce control or stabilizer is used to vary the pressure in the unce chamber.

To vary the pressure in the bounce chamber use is made of the ct that during part of the stroke the pressure in the chamber is higher an the pressure in the engine case, and for the other part it is below . Air can then be transferred from the bounce chamber to the engine se or vice versa.

It is believed that the free piston gas generator-turbine power ant presents many advantages for marine propulsion service. Some of ese advantages are as follows:

(1) Flexibility of Installation - The gas generators can be arranged in the engine room according to the available space.
(2) Foundations - The absence of vibration, due to the well balanced operation of the gas generator, makes unnecessary the use of heavy or special foundations. All that is needed is to support the weight of the equipment.
(3) Production - Manufacturing and production simplicity are obvious; no large forged or cost parts are required.
(4) Dismantling - The component parts of the gas generator are light in weight, the heaviest moving part weighing only 650 lbs., and the heaviest stationary part requiring maintenance weighs less than 1,400 lbs. The total weight of this gas generator is approximately 18,000 lbs., and with

only four bolts required to hold down the machine, it can be easily removed and a spare installed in its place.

The assembly of the generator is very simple. Pistons are accessible in approximately 20 minutes.

(5) Maintenance - The maintenance of a power plant involves different aspects: labor, spare parts and overhaul time.

The simplicity and small number of parts of the gas generator greatly reduce the labor necessary for maintenance. Since the moving parts are few the number of spares is also small, which not only means less cost but also less weight and space taken up aboard ship. The units being standard permit complete interchangeability of all spare parts.

For the same reason, and also because of the independence between each gas generator, the down time is kept to a minimum. Individual units can be overhauled at sea.

(6) Fuels - The gas generator is very well adapted to combustion of heavy fuels. It is a highly supercharged engine giving large quantities of excess air in scavenging and it includes no moving parts, such as valves, in the exhaust gas circuit. Lubrication of the piston rings and cylinder liners is made by an independent oil pump and the oil is dispensed within the cylinder without recirculation. There is no danger of contamination of oil by sulphur.

(7) High Efficiency - The inherent efficiency of the cycle is very high. The pressures and temperatures reach valves not obtainable in the case of diesel engines. The high pressures and temperatures are made possible by various factors. The absence of bearings and heavy linkage permits the use of higher compression pressures. Heat losses through the walls are small because of the small surface of the combustion chamb (opposed pistons). The large excess scavenging air provides good cooling of the hot surfaces and carries the heat with it through the turbine. Friction losses are small and the high compression ratio gives a high adiabatic efficiency.

(8) Critical Materials - The gas to the turbine is low in both pressure and temperature, 45 psig and 875 F respectively, at full load and it is therefore possible to use much less in the way of critical materials than is normal for open cycle gas turbine requirements and, at the same time, high thermal efficiency is maintained with good reliability and long life. The critical materials, namely nickel, chromium, copper, cobal etc., required are so small in quantity that their requirement can be regarded as negligible.

Before shipboard installation of the free piston-gas turbine power plant extensive shop testing at Cleveland Diesel was required. This included a 500-hour reliability test of the first free piston-gas generator using heavy fuel and also a 100-hour test of each gas generator-turbine combination. Photographs of the test stand installation are included as plates (13) and (14).

Future Engine Improvement Program

Future planning by the Maritime Administration to improve power plant performance includes the following:

(1) The design, manufacture and testing of a closed cycle gas turbine power plant suitable for use with a gas cooled nuclear reactor; and
(2) The procurement, installation and service evaluation of a completely new free piston power plant using the most advanced designs evaluated in the interim and utilizing an after-burner to increase the power output with little increase in the physical size of the plant.

Rotary Compressor Closed Cycle Gas Turbine Plant Program

In power plants of this type, the gas is recirculated through the plant in a closed loop instead of exhausting to the atmosphere after a single passage as in the open cycle version. This power cycle offers several advantages for marine propulsion applications. It has high thermal efficiencies at both rated power output and partial loads; its power output is independent of atmospheric conditions; air ducting requirements and rotating machinery size and weight are minimized by recirculation of the cycle fluid and the use of higher gas pressures; and it is supported by more than fifteen years of European experience including research, development, test, and service use in land power generating applications. The primary reason for a Maritime Administration program in this field, however, is the higher inherent adaptability of closed cycle gas turbine plants to the utilization of nuclear energy. While existing nuclear power plants employ a steam power cycle, a nuclear closed cycle gas turbine plant of comparable rated power output would have higher efficiencies throughout the operating range with decreased weight and space requirements.

Proposals have been received from five organizations in response to an invitation for such a power plant sent to all of the qualified organizations in the country by the Maritime Administration. Contract negotiations are now underway for the design, construction and testing of a closed cycle Power Plant suitable for use with a nuclear reactor.

Free Piston Generator Gas Turbine Plant Improvement Program

It is expected that the service performance of the WILLIAM PATTERSON installations will be sufficiently successful to justify the procurement, installation, and service evaluation of a completely new free piston gas generator - turbine power plant using the most advanced design evaluated in the interim. This plant would be preferably of American materials and manufacture and would be installed in a new ship selected to make full use of the improved propulsion machinery. The new plant would include an after burner to introduce and burn additional fuel in the exhaust gas between the gas generators and turbine, using the oxygen still available in the exhaust for producing additional heat and gas flow to the turbine. This method produces greater power from a given size of power plant. It is intended primarily as a method of obtaining peak power with only a minor increase in plant cost, although it can be used for continuous power when and if desired.

The Engine Improvement Program outlined in the preceding paragraphs is, in general, an over-all effort to incorporate the benefits of recent advances in marine power plant engineering into the merchant fleet. It is expected that the resulting improvements in ship performance will more than repay the required investment of funds, time, and effort. The two gas turbine propulsion plant conversions resulting from the action of the Evaluation Board are major steps in this direction.

Application of Heavy Fuel Oil

It is essential to note that the propulsion machinery of all four conversions is required by specification to be capable of satisfactory operation on Bunker "C" (No. 6) fuel, the most economical fuel available in all ports. This type of fuel is in common use for ships' boilers but has had very little application to diesel engines or gas turbines in this country. Some effort has been made by European operators to use this cheaper fuel in diesel powered ships with good economic results.

In these developments special emphasis is placed on the treatment and purification of fuel oil to minimize operational difficulties and to lower maintenance costs. The degree of difficulty encountered in adapting the conversion propulsion machinery to residual fuel operation is highest in the third (EC2-G-8f) conversion employing rotary compressor open cycle gas turbine propulsion. This conversion includes equipment for the removal of machinery surface deposits in addition to the maximum amount of fuel treatment equipment among the four ships. The second (EC2-M-8b) and fourth (EC2-G-8g) conversions present less difficulty, and have been equipped with similar fuel treatment systems, except that no automatic viscosity control unit has been included on the fourth conversion. No modifications to the fuel system of the first (EC2-S-8a) conversion were required.

The economic advantages of using heavy (residual) fuel in diesel propelled or gas turbine propelled ships, as well as in steam propelled ships, will be demonstrated to American ship operators by accumulating accurate fuel economy data under carefully controlled conditions. An indication of these advantages is shown by the comparison of recent price quotations on marine diesel vs. marine fuel oil.

Dollars per bbl.

Port	Fuel Oil	Diesel Oil
Philadelphia	$3.05	$4.48
Baltimore	3.05	4.48
Beaumont	2.60	3.82
Kingston, Jamaica	3.02	4.40

It is extremely gratifying to advise that the Industry has enthusiastically and wholeheartedly cooperated in this program. The reasonableness of bids and proposals has reflected an understanding of value of these conversions and power plant developments. It would seem that each dollar of the Government's expenditure is receiving in return more than the usual value in engineering and manufacturing skill.

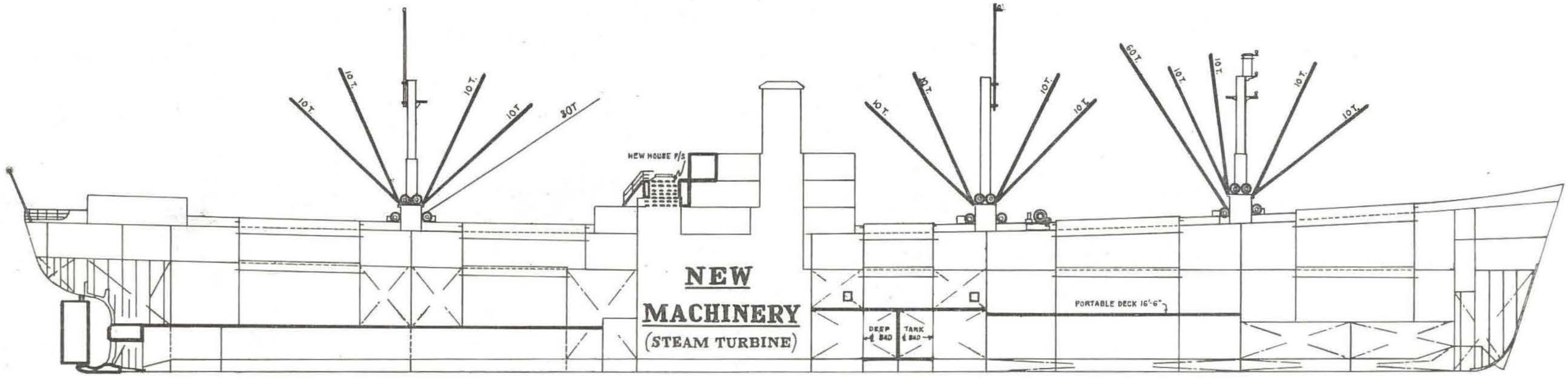
A high degree of interest in and enthusiasm for this program has been generated in the technical and public press, both in the United States and abroad. It is evident that the over-all program is regarded as a forward step of considerable magnitude in merchant ship propulsion and cargo handling equipment development and application.

The service operational evaluation of the four conversions will demonstrate the following:

1. Feasibility of further conversions of Liberty ships.
2. Manner in which conversions can be made most economically.
3. Types of available propulsion plants to be used for future conversions.
4. Feasibility and economics of using gas turbine power plants in our future construction.
5. Practical application of proposed modifications to cargo handling equipment for future installations.

Placed by careful selection in the hands of competent United States flag operators, the four current conversions will provide an experimental laboratory and proving ground under service operating conditions for attaining these objectives. An incentive has been provided in the cargo handling gear improvement program to make available for United States marine installations the superior materials handling equipment developed for shore applications. The engine improvement program in its current and proposed phases provides a basis for additional progress beyond these immediate objectives by making available, within the United States, proven marine propulsion plants of superior performance characteristics. The one-year service evaluations are directed toward the establishment of conclusions of maximum validity and applicability. It was considered desirable to assign these ships in pairs, that is, the steam turbine and diesel conversions for comparison of cargo gear and sea-keeping evaluation, and the two gas turbine conversions for propulsion plant evaluation. The ships will consequently compete against each other under similar operating conditions in the same trade. This approach will not only provide proper evaluation, but will also serve to disseminate information directly to the operators of the United States Merchant Marine.

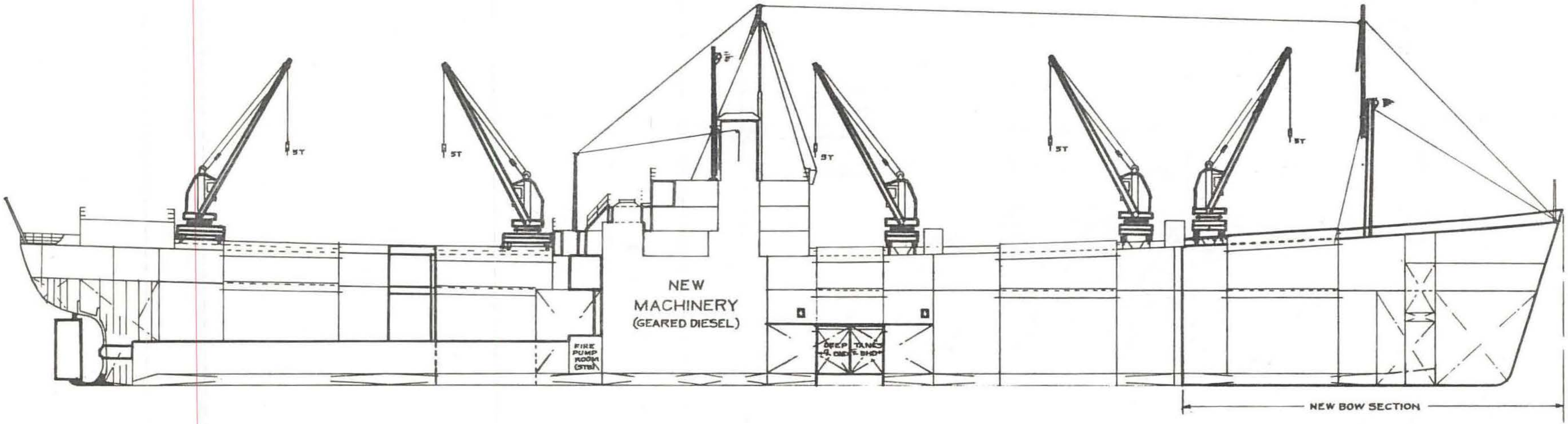
APPENDIX I



LEGEND
HEAVY LINE --- NEW WORK
LIGHT LINE ---- EXISTING

DESIGN **EC2-S-8a**
~LIBERTY SHIP CONVERSION-STEAM~

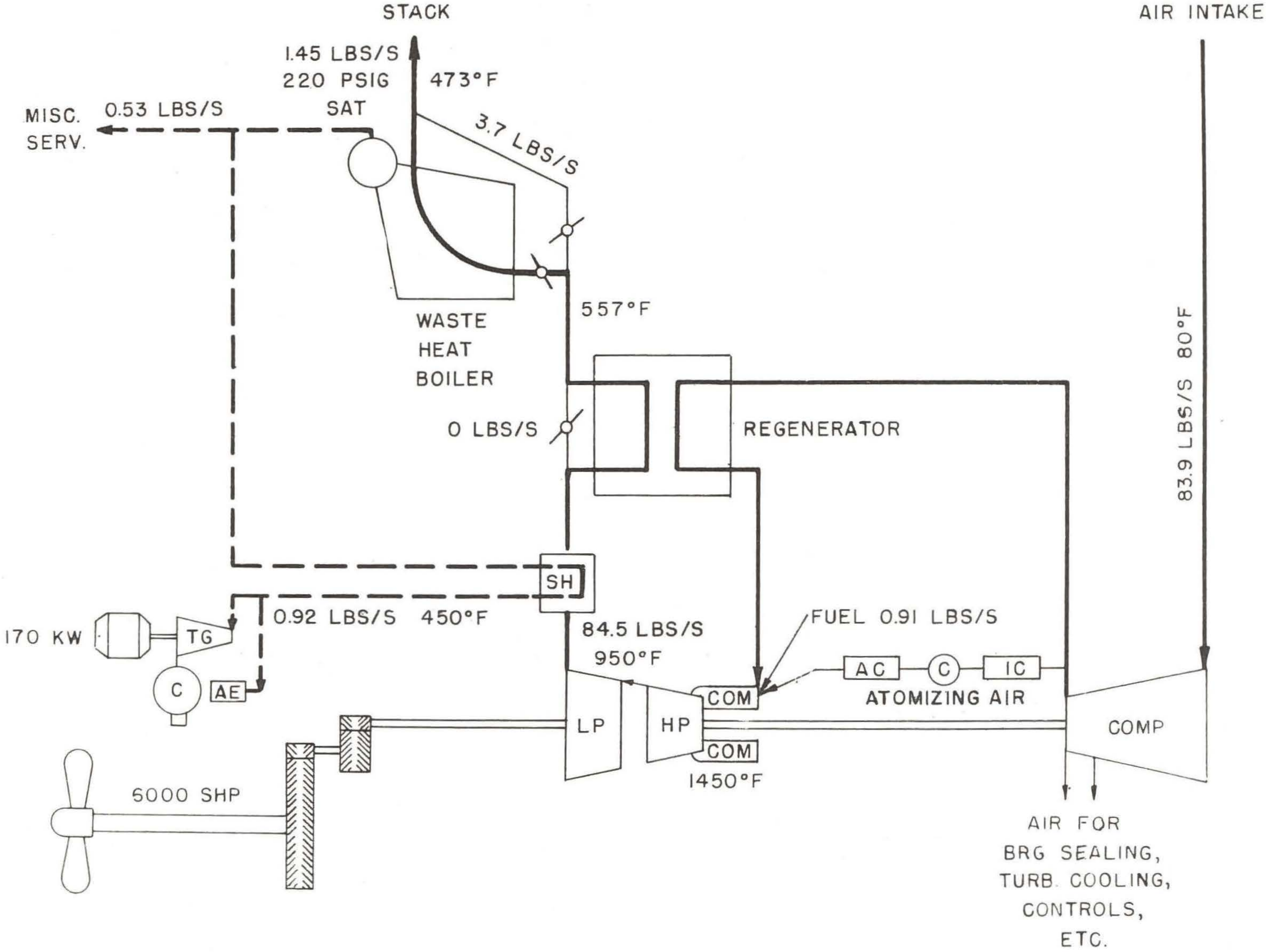
APPENDIX 2



→ LEGEND ←
LIGHT LINES - EXISTING
HEAVY LINES - NEW WORK

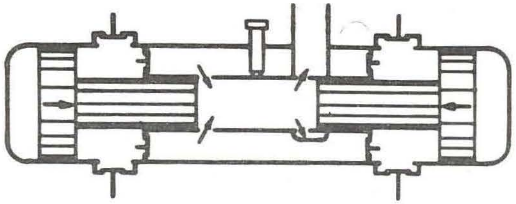
DESIGN EC2-M-8b
(LIBERTY SHIP CONVERSION-DIESEL)

APPENDIX 3



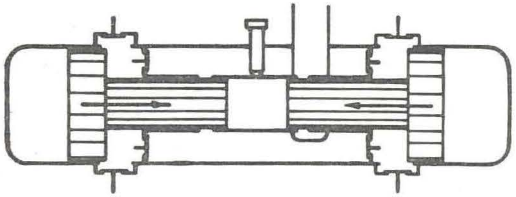
FLOW DIAGRAM – ROTARY COMPRESSOR OPEN CYCLE GAS TURBINE PLANT

APPENDIX 5



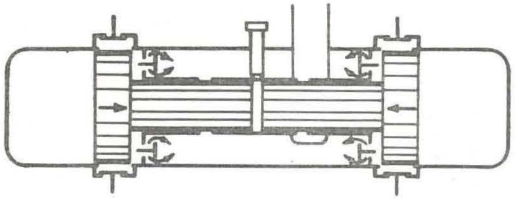
OUTER DEAD POINT

The pistons, under bounce air pressure, start toward the center. The automatic compressor air intake valves are closed. Scavenging is practically completed.



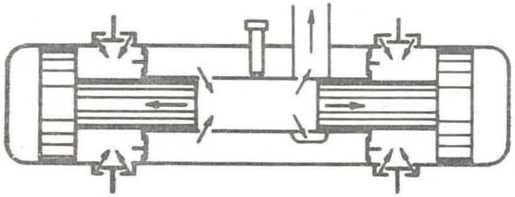
INWARD STROKE

The exhaust and intake ports are closed and compression in the power cylinder begins.



INNER DEAD POINT

The automatic compressor air discharge valves have opened and are delivering the scavenging air to the engine case. Fuel is injected into the power cylinder and combustion begins. The pistons move away from the center; the compressor air delivery valves close.

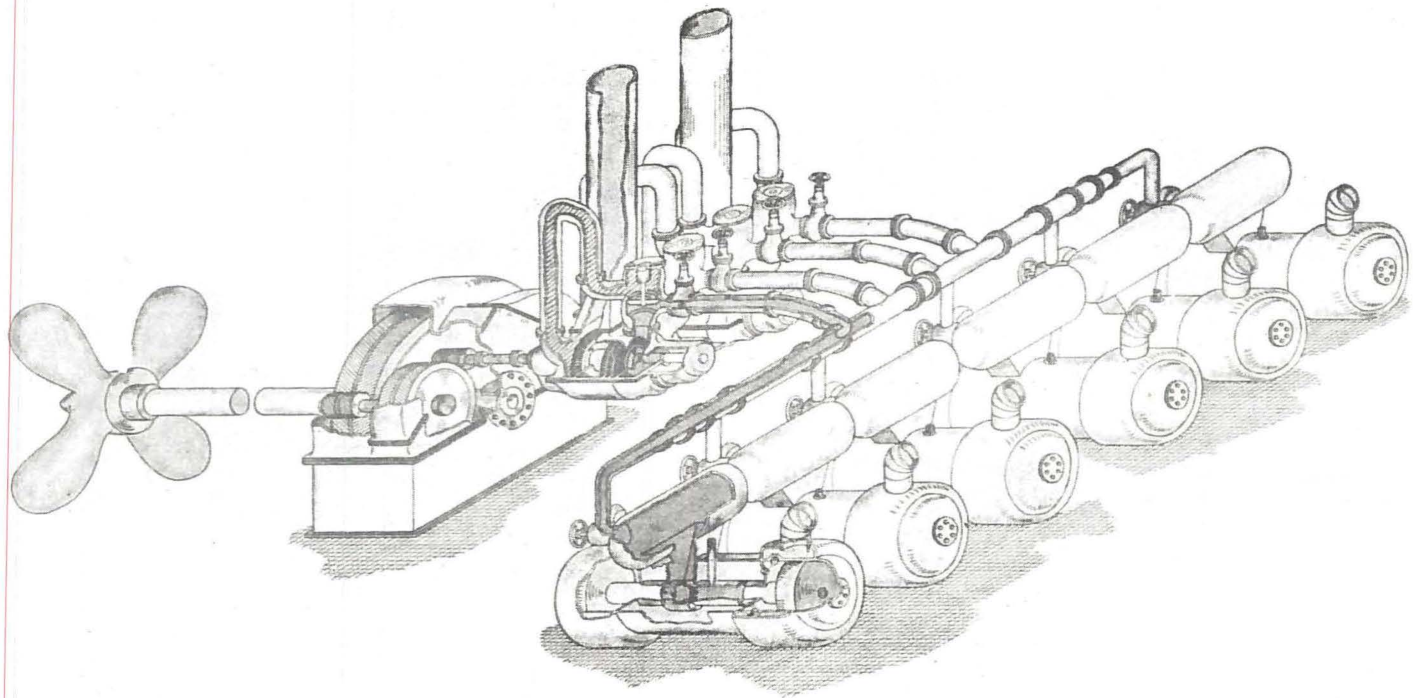


OUTWARD STROKE

Pistons move apart, the compressor air inlet valves open. The exhaust and then the inlet parts are uncovered. The mixture of scavenging air and exhaust gases flow to the turbine. The power cylinder is filled with fresh air.

OPERATING CYCLE OF FREE PISTON GENERATOR

APPENDIX 6



FREE PISTON GENERATOR GAS TURBINE PLANT

APPENDIX 7

FISCAL SUMMARY AS OF SEPTEMBER 1, 1957

Contractor	Contract No.	Contract Price
SS BENJAMIN CHEW		
Bushey & Sons	MA 868	$ 1,062,000
MS THOMAS NELSON		
Bethlehem Steel	MA 871	3,035,000
GTS JOHN SERGEANT		
Newport News	MA 1071	2,450,000
Gibbs & Cox, Inc.	MA 853	81,219
S. Morgan Smith	MA 893	118,200
General Electric Co.	MA 894	811,428
GTS WILLIAM PATTERSON		
Bethlehem Steel	MA 1078	1,857,999
J. J. Henry Co.	MA 870	78,809
General Motors Corp.	MA 895	1,228,723
Total Contracts		$10,723,378
GENERAL		
Transferred to David Taylor Model Basin		60,000
Changes, purchase orders, etc. to date		1,470,931
Total Obligations		$12,254,309
Allotment		12,300,000
Less Total Obligations		12,254,309
Unobligated-Reserve for Changes and Developments		$ 45,691

United States Maritime Commission
Division of Public Relations

PHOTOGRAPHIC FILE

NEGATIVE No. **4422** See 4423

SUBJECT: **SHIP TYPES - Liberty**

LOCALE: **New York Harbor**

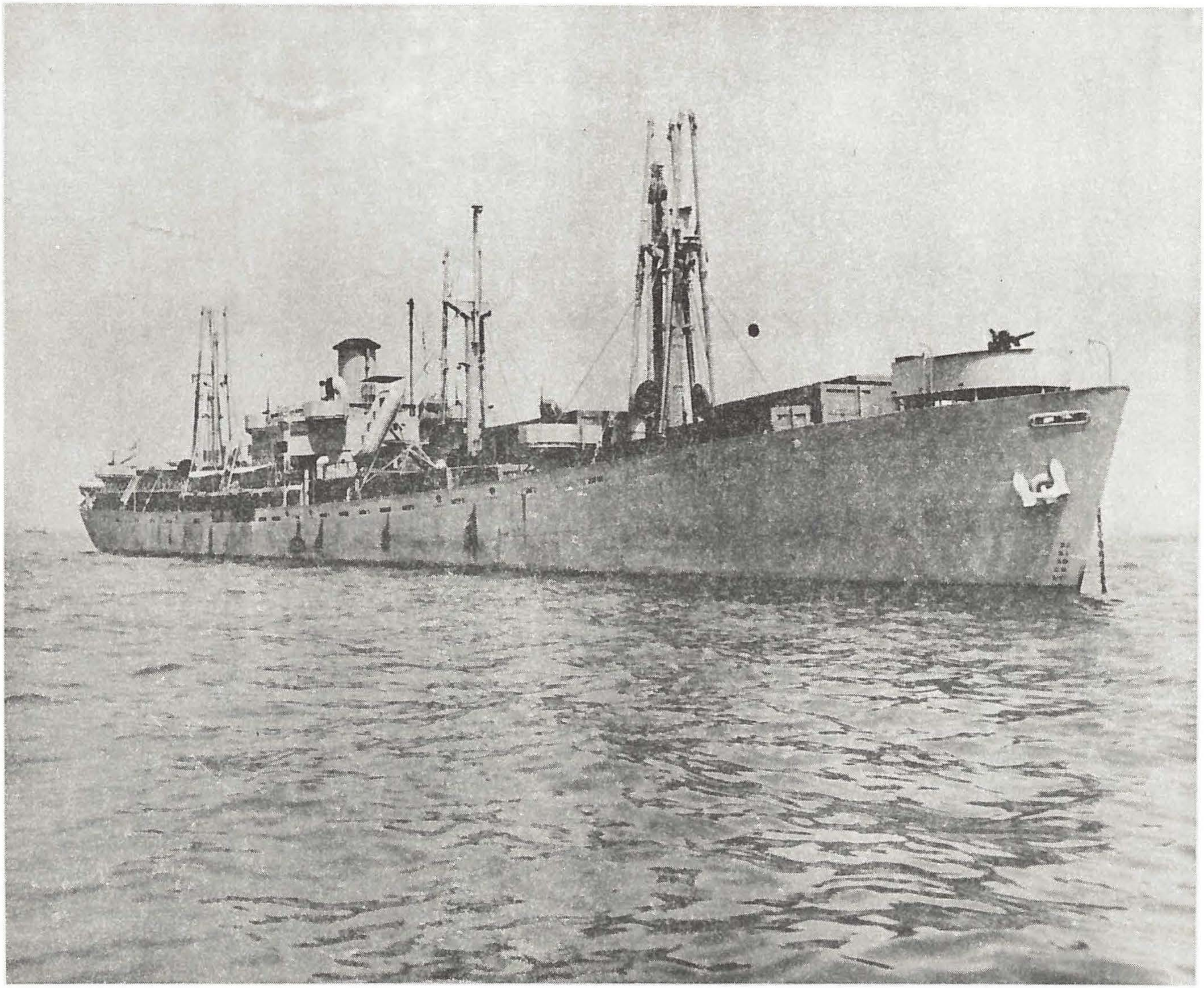
DATE: **September 1944**

DESCRIPTION

Liberty ship, with full deck load at mooring in lowering neatest possible deck stowage.

RESTRICTIONS GOVERNING USE

PLATE 1



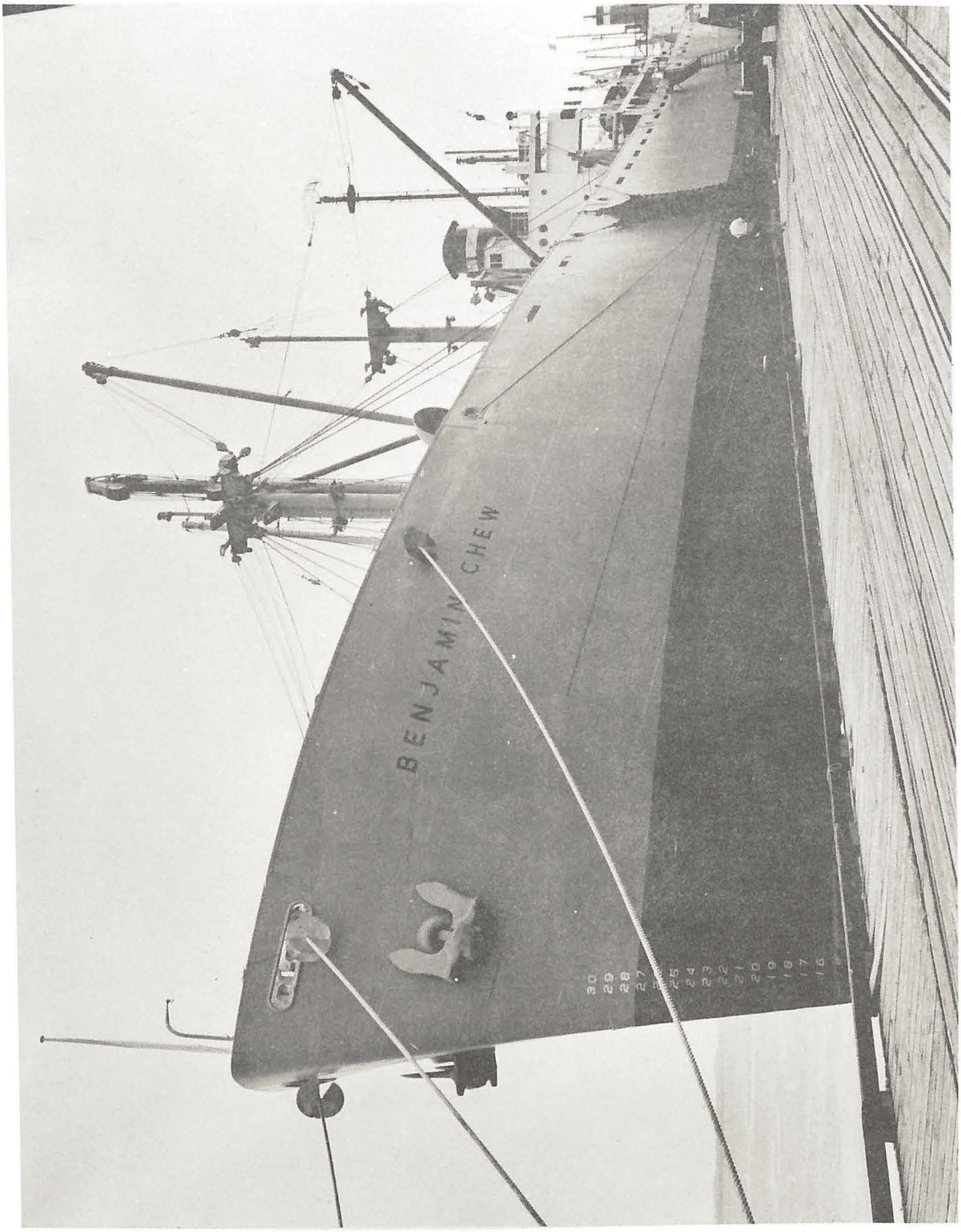


PLATE 2

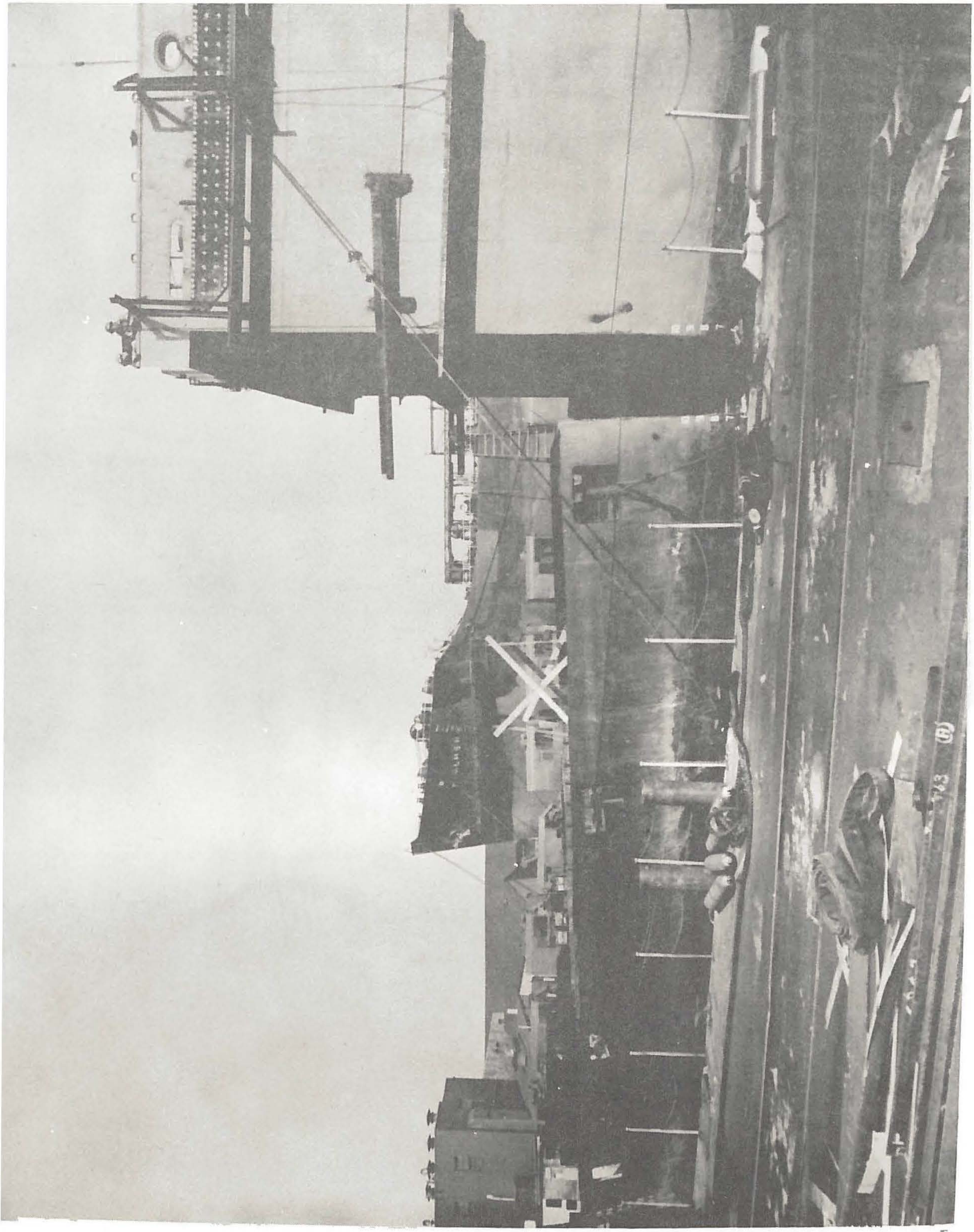


PLATE 3

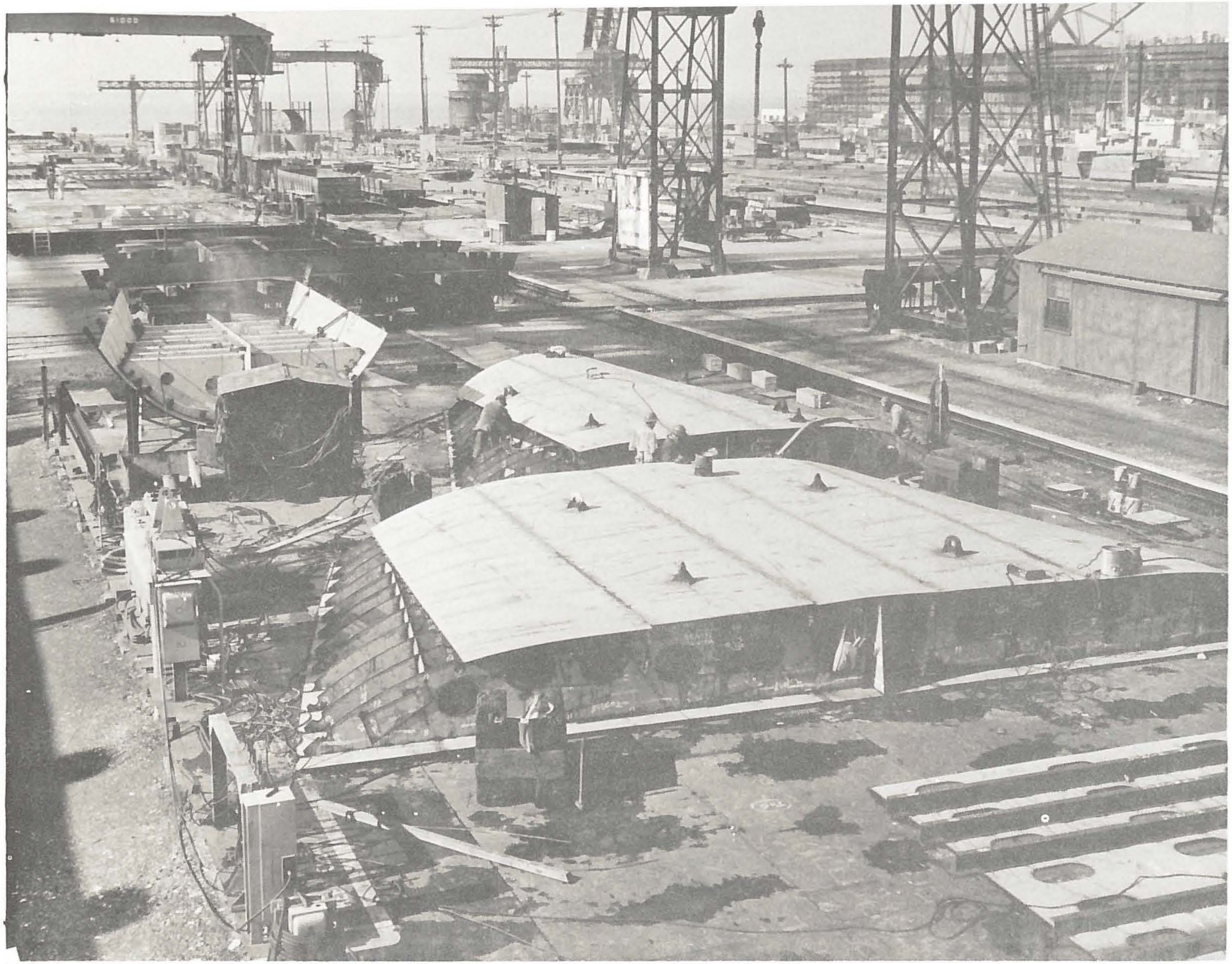


PLATE 5

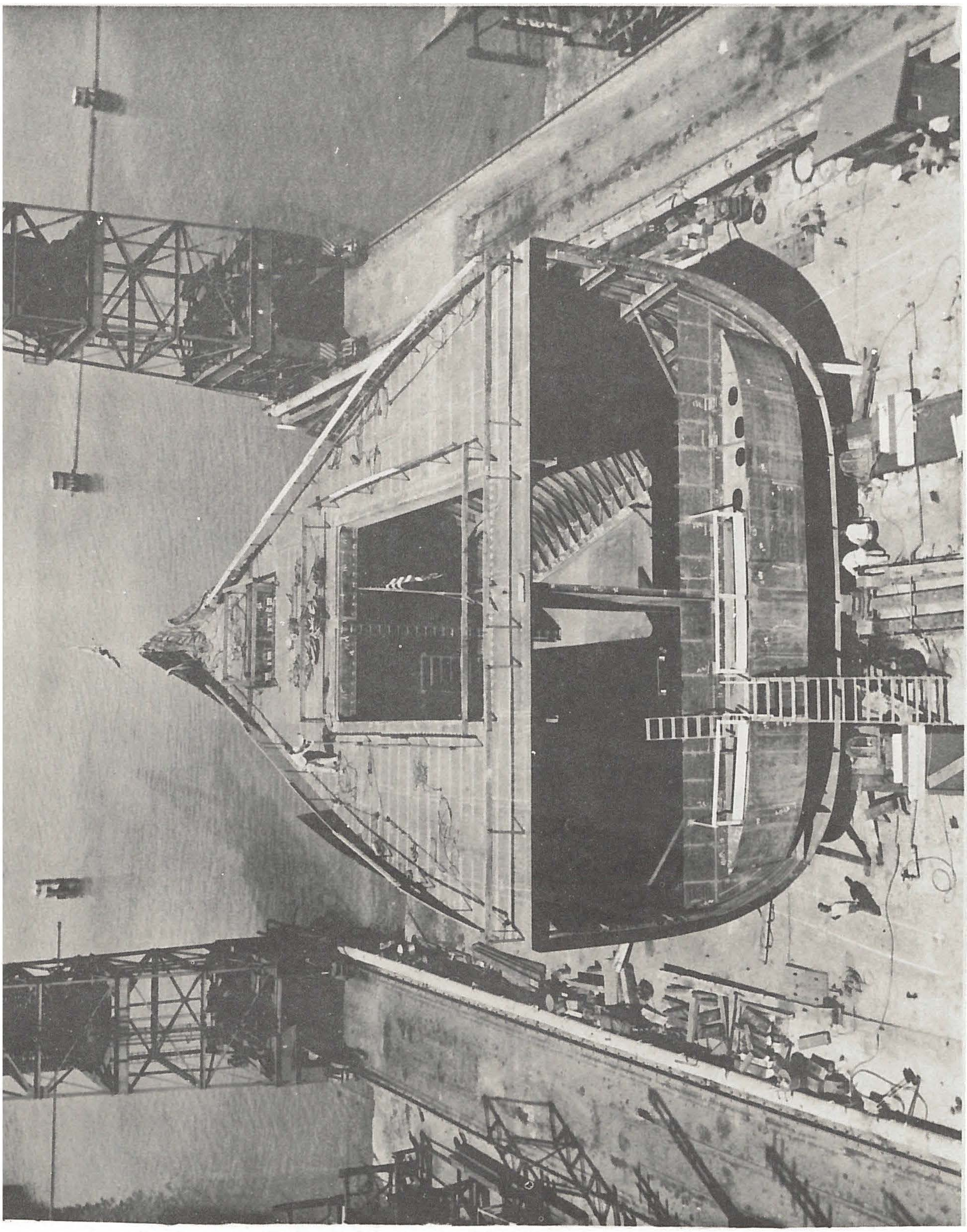


PLATE 6

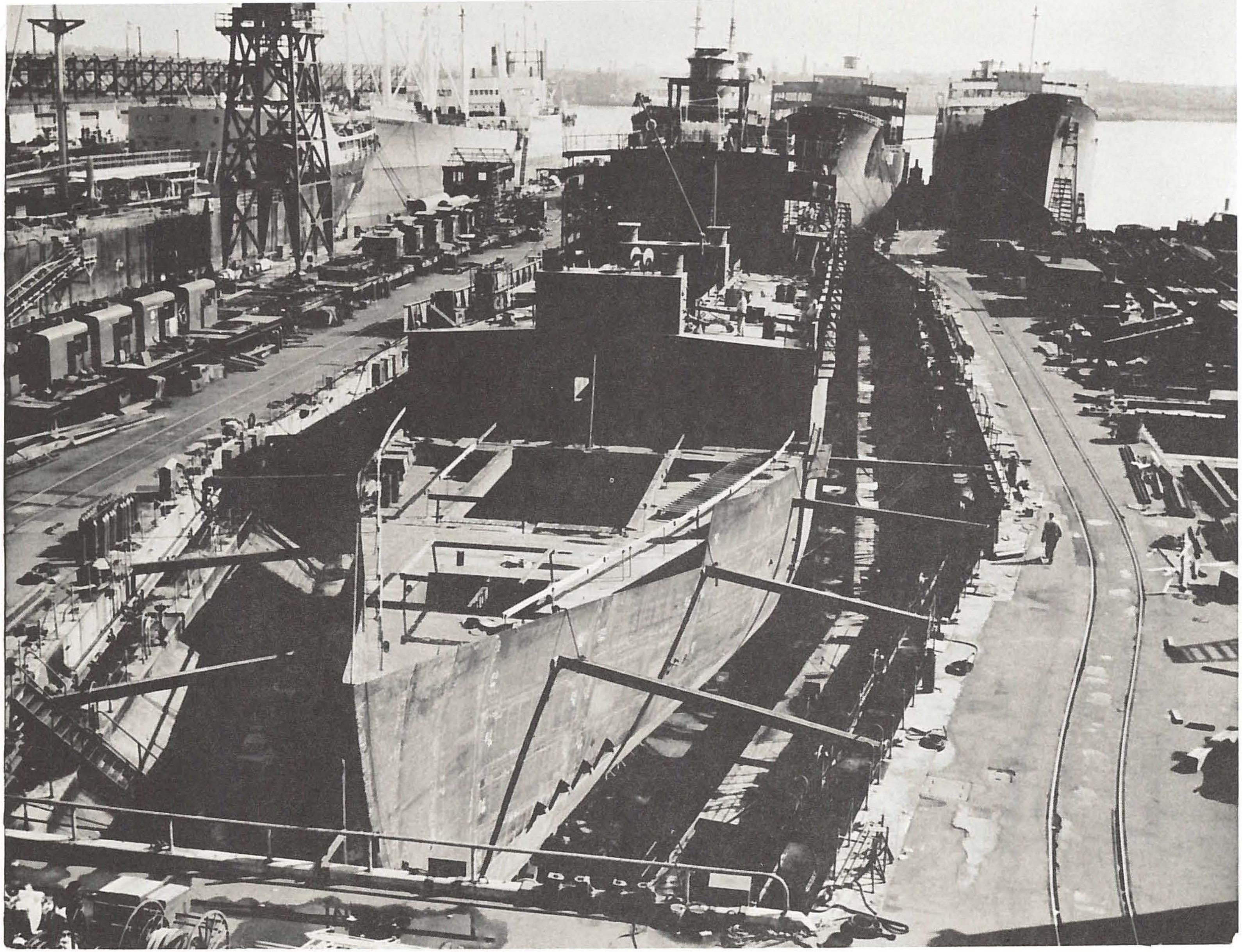


PLATE 7

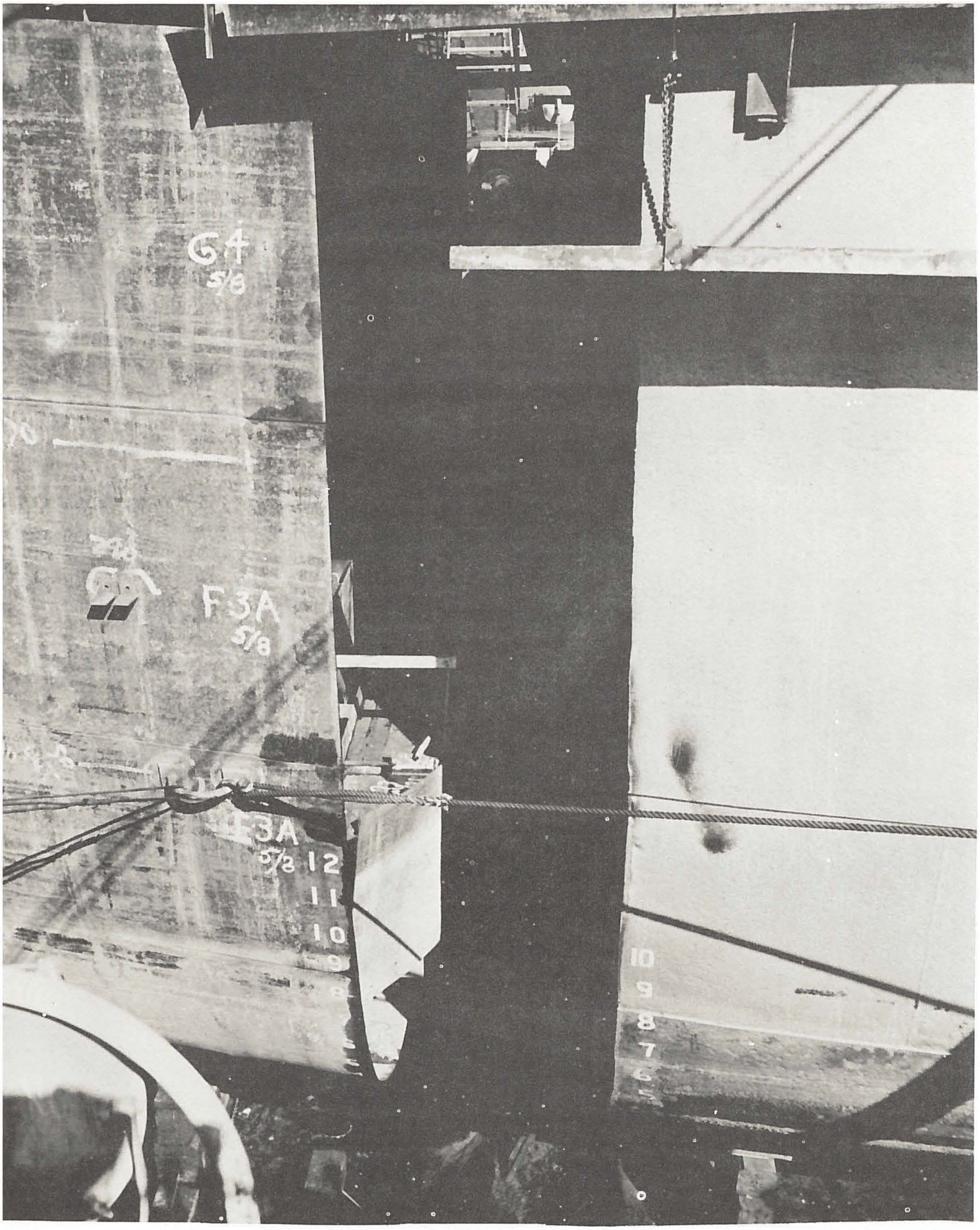


PLATE 8

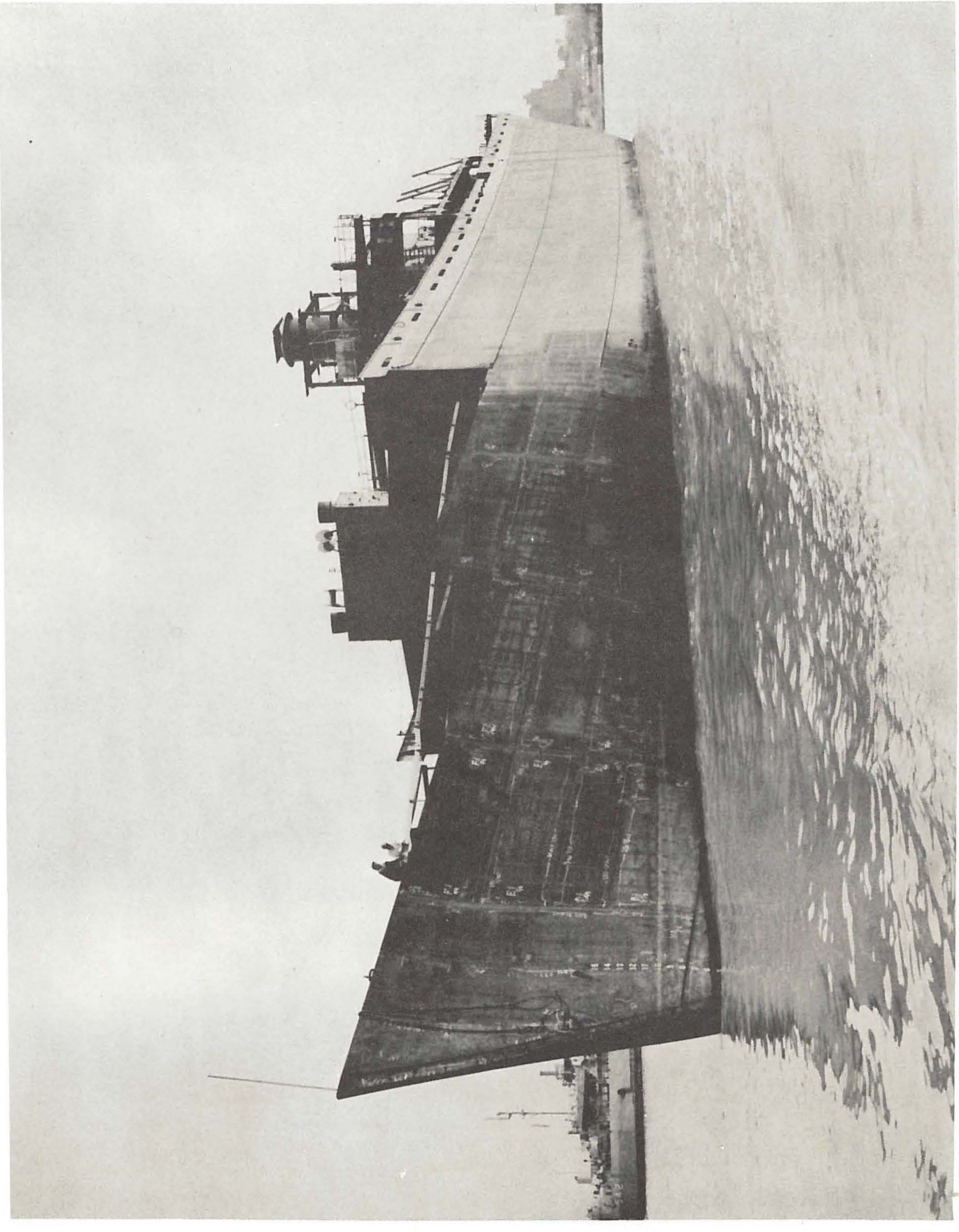


PLATE 9

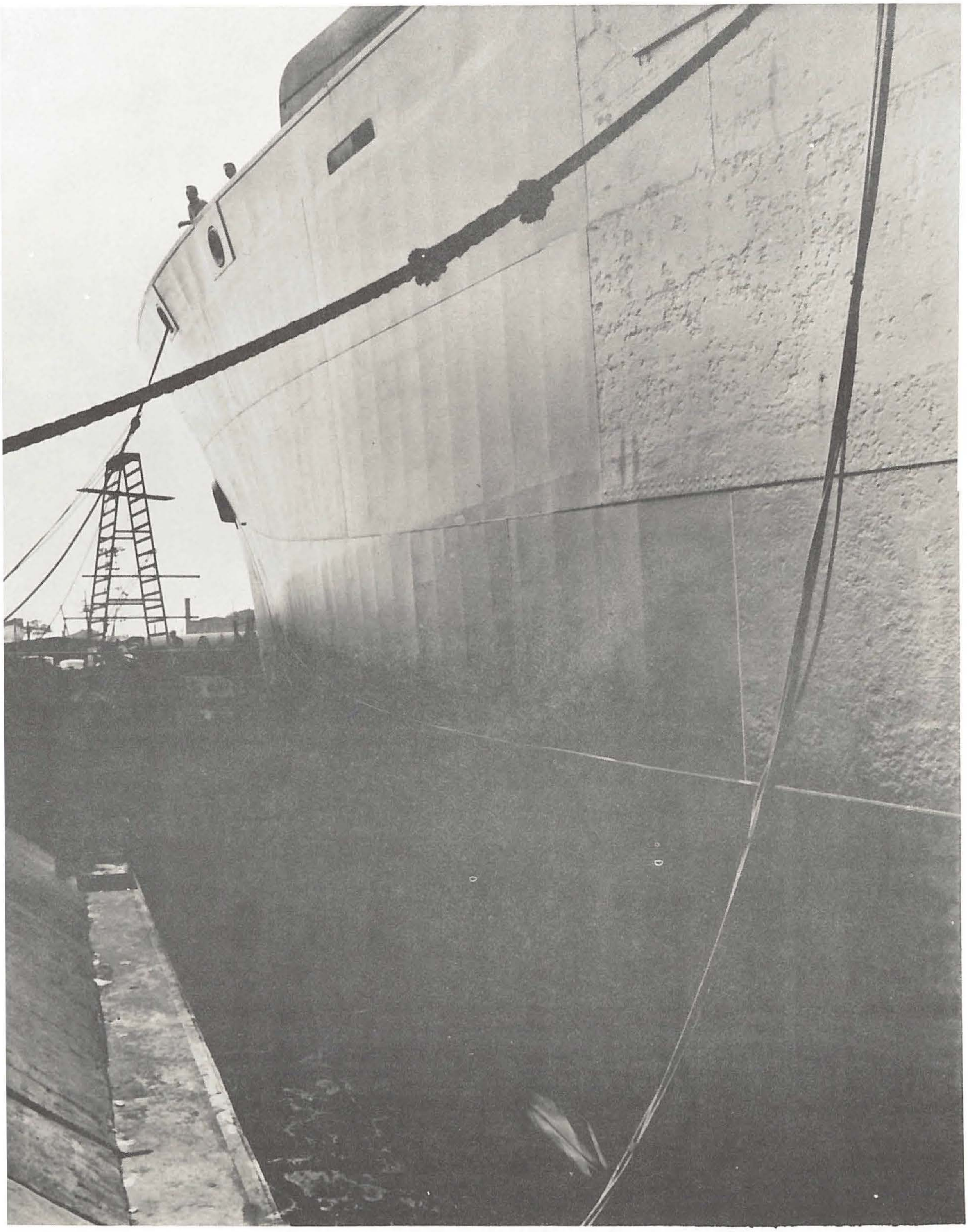


PLATE 10

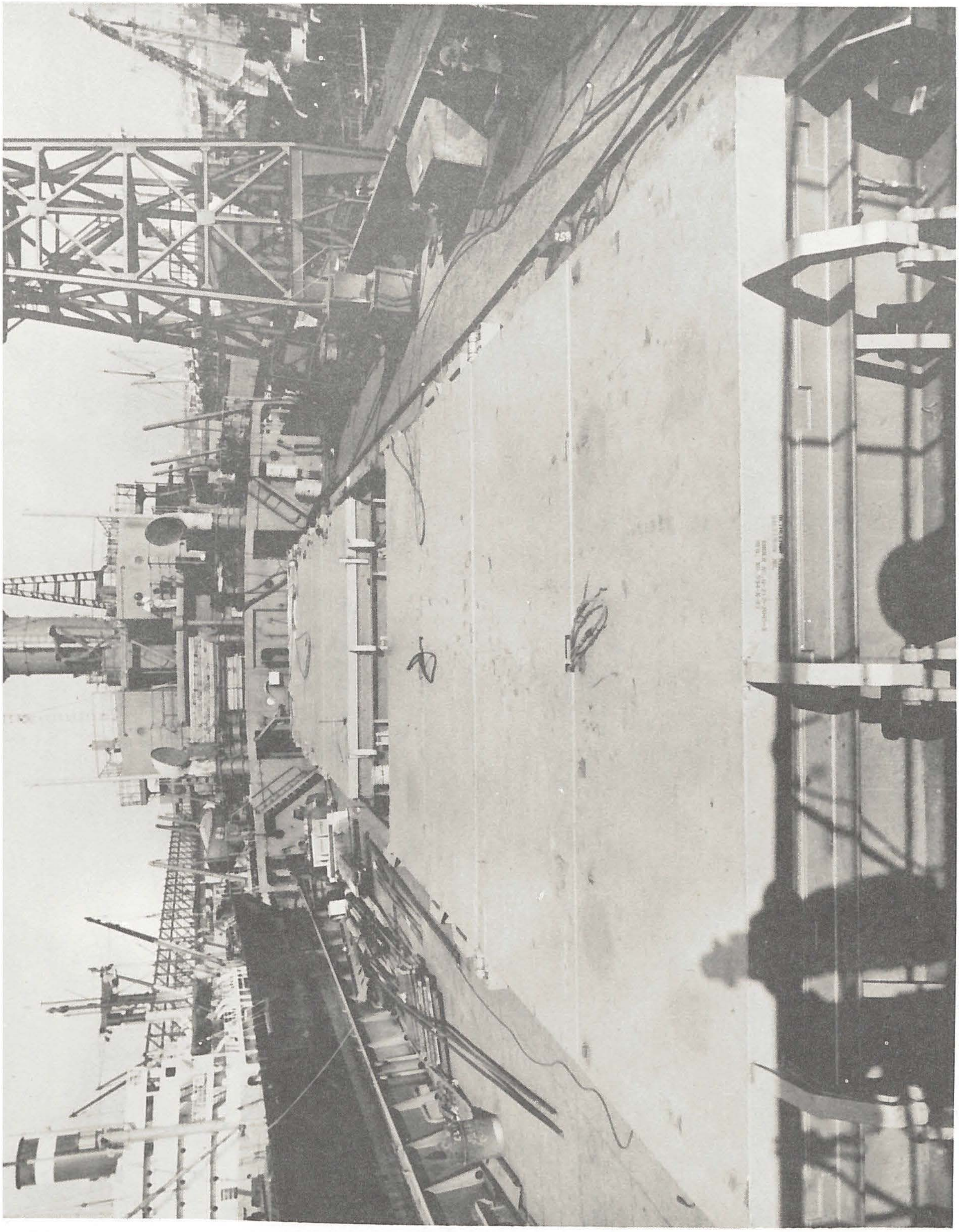


PLATE 11

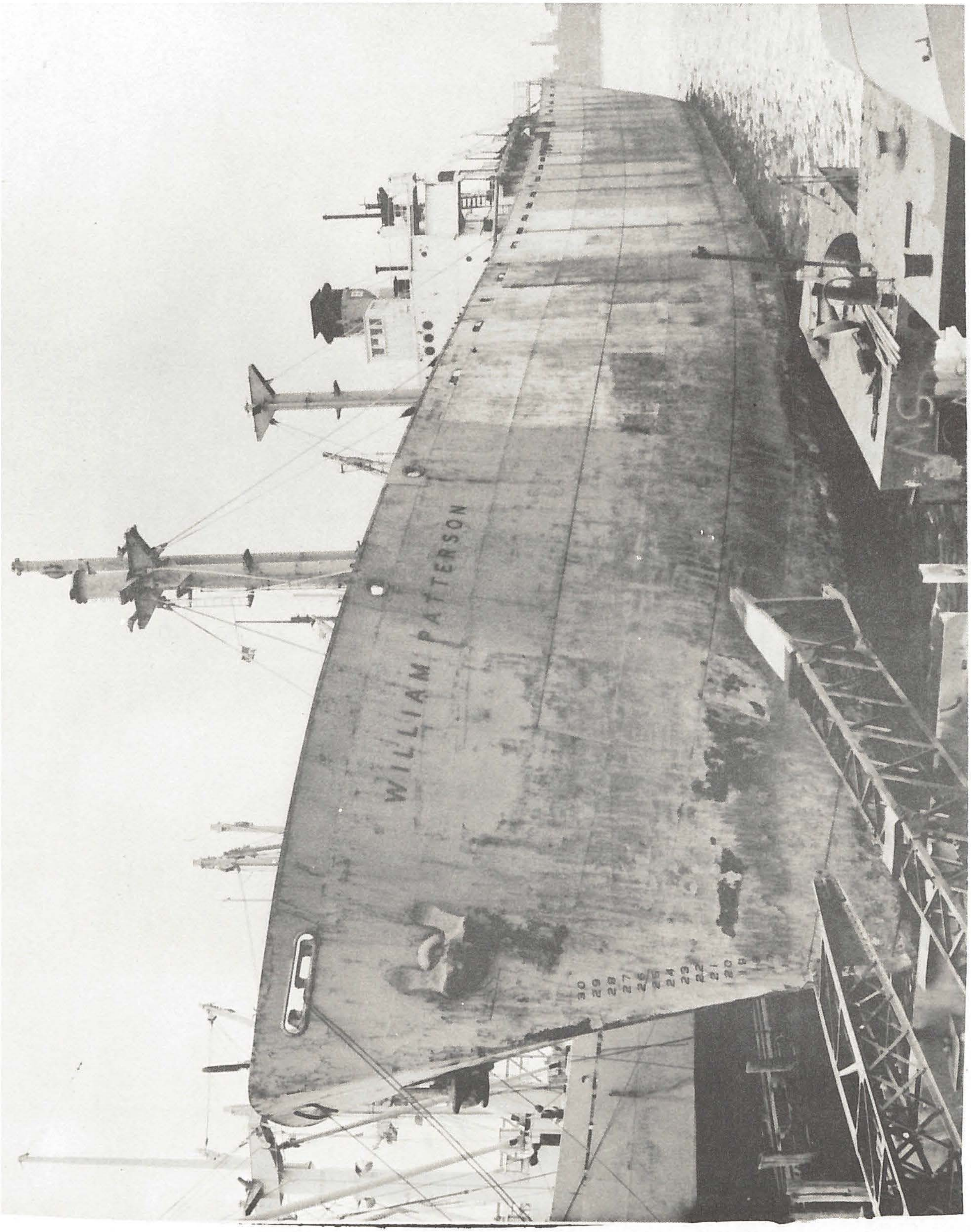


PLATE 12

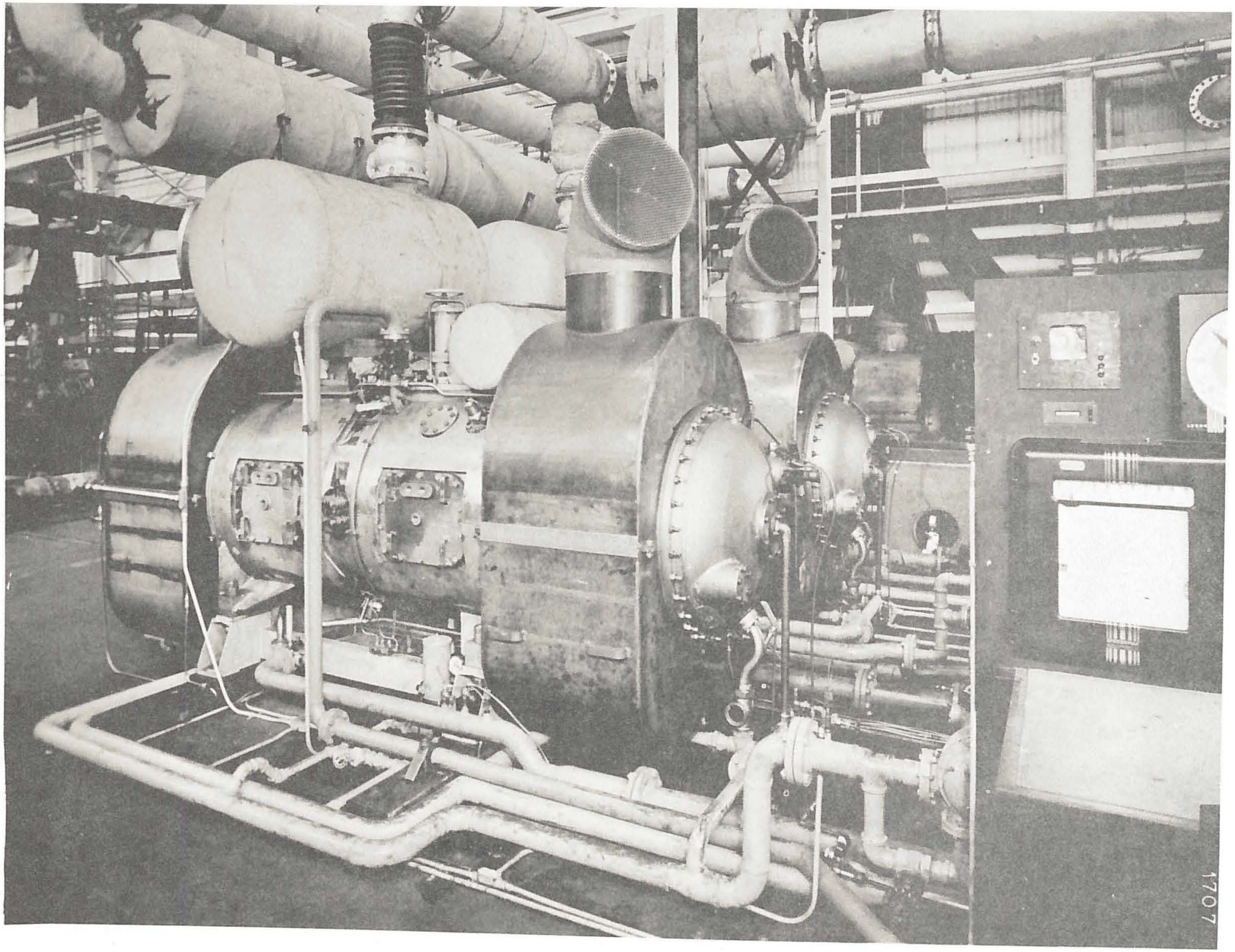


PLATE 13

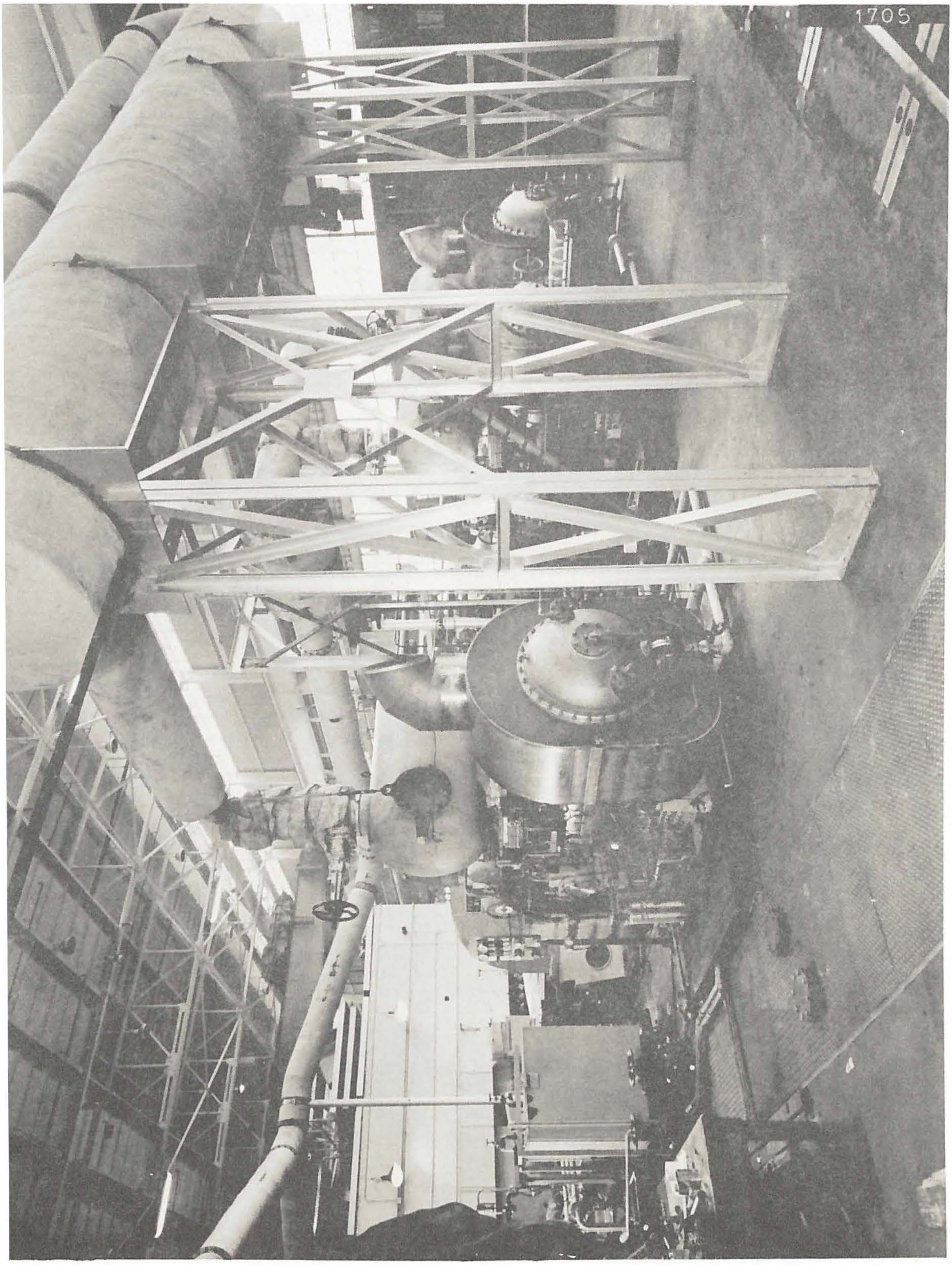


PLATE 14

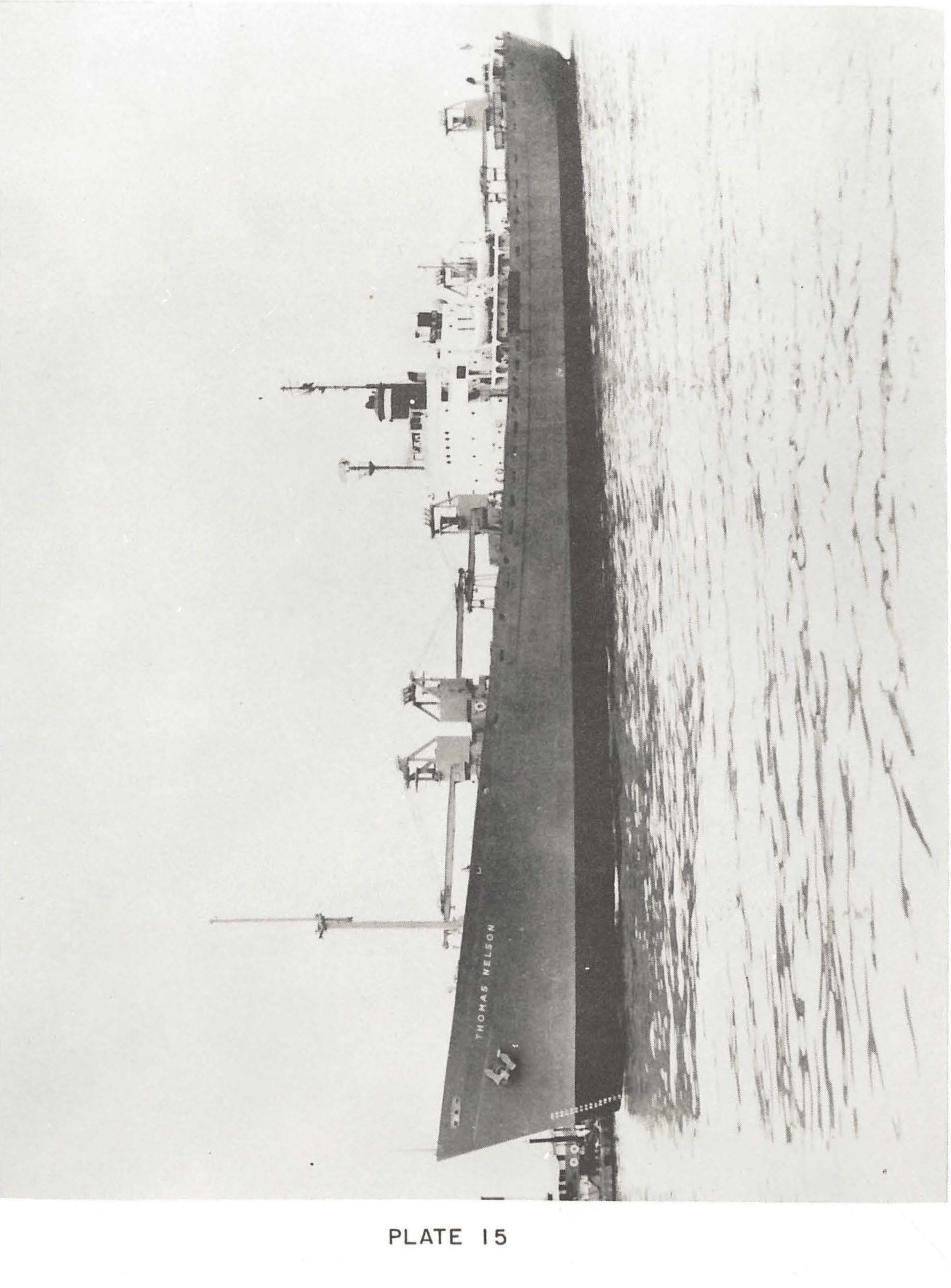


PLATE 15

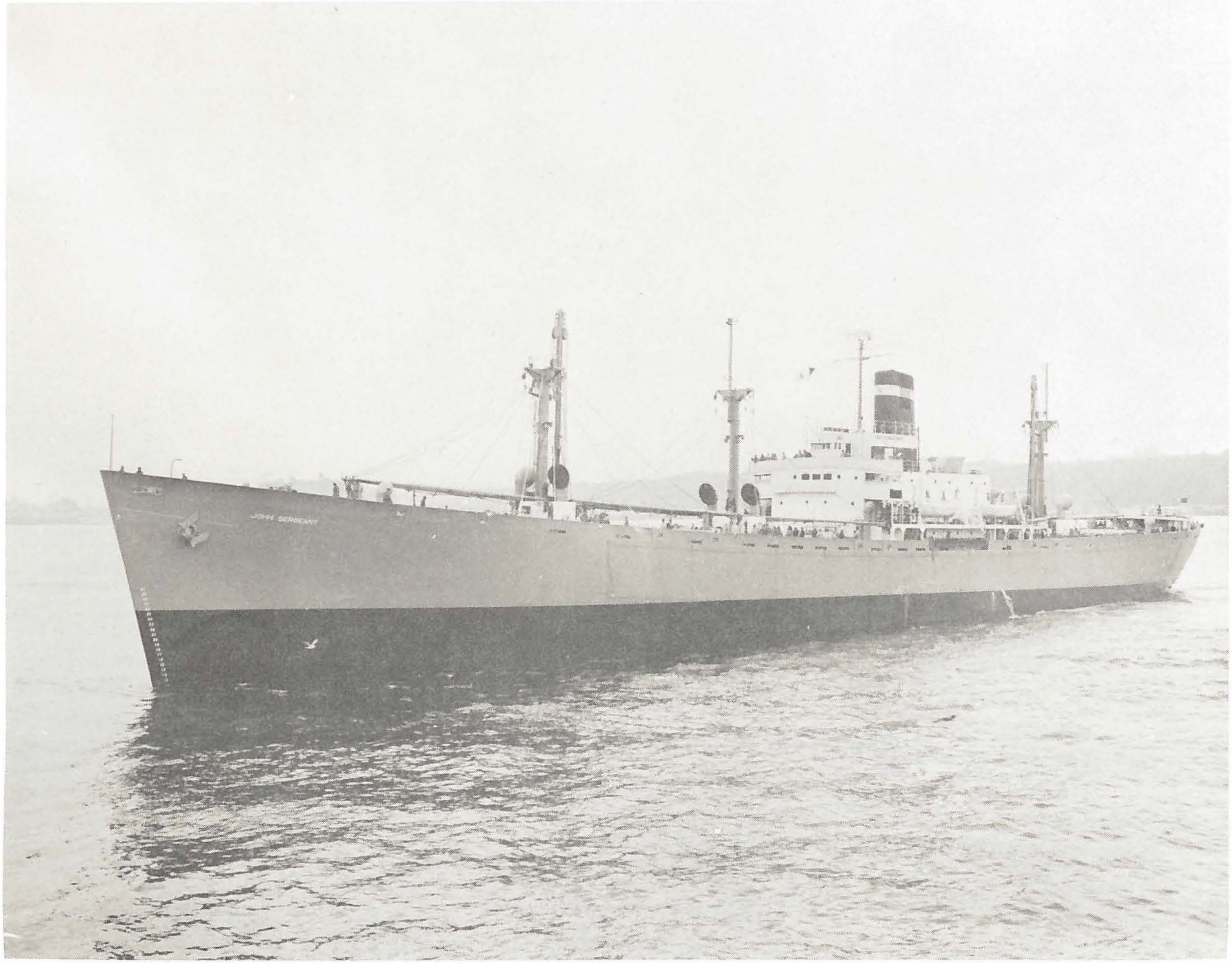


PLATE 16

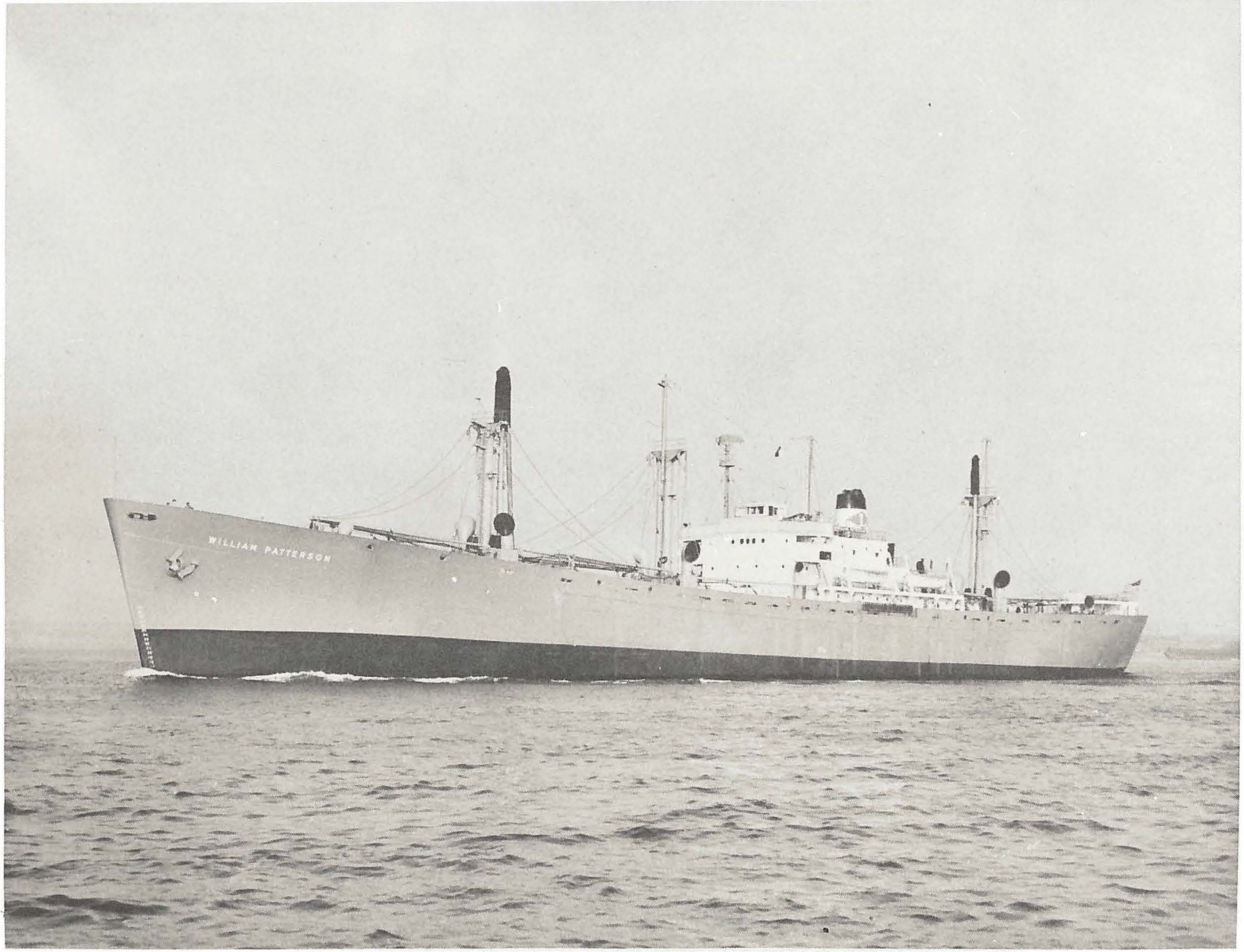


PLATE 17